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INFORMATION TRANSMISSION IN OPERATOR
REPORTS OF EQUIPMENT MALFUNCTION

May 1967

Prepared for

Aerospace Medical Research Laboratories
Aerospace Medical Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

by

Harold R. Leuba, Ph.D.

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This study established the feasibility of using information measurement techniques to analyze reported maintenance data. Failure data on two systems were analyzed: (1) the ASB-4 Bomb/Navigation System of the B-52, and (2) the MA-1 Fire Control System of the F-106. The ASB-4 data (flight-line reports) and the ship data for the MA-1 contained written descriptions of the malfunction symptoms. To make these data amenable to multi-variate uncertainty analysis, a coding scheme designed to retain the grammatical form and content of these symptom reports was used. The F-106 organizational (flight-line) data are already coded (according

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(over)

to ADC 66-28 symptom codes) which make them directly amenable to information analysis.

In analyzing the ASB-4 data, it was found that the subject of the reported symptom was most indicative of the unit containing the malfunction, while the predicate phrases and modifiers showed a relationship with repair time. The F-106 data indicated a strong relation between pilot and symptom, although the nature of this relationship cannot be determined from the available data.

Some pilots may not be reporting symptoms when they should be. Introducing a training program on Symptom Reporting Procedures should markedly increase systems effectiveness. It appears that a change in job assignment and personnel evaluation procedures could have a large impact on maintenance workload. Additional data are required before specific recommendations can be made, but the results of this study are highly suggestive of the type of data needed to answer the questions raised.

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INTRODUCTION

When operators complain about equipment performance, they are trying to tell maintenance men something about how the equipment is functioning; they may also, albeit unwittingly, tell analysts of maintenance data something about how they, the operators, are performing. Simultaneously, when maintenance personnel perform maintenance actions, the equipment "tells" them how it is performing, and the reported actions tell analysts of maintenance data something about how the maintenance men are performing.

Figure 1 is a symbolic representation of this communication of information, as it is reviewed by an analyst of maintenance data. In Path 1, equipment malfunctions are transformed into symptoms; in Path 2, symptoms are observed and reported to maintenance men by operators; in Path 3, maintenance men use test equipment, ground power sources, etc., to diagnose the equipment; in Path 4, maintenance men fill out reports telling analysts what maintenance was required; Path 5 indicates reported malfunctions are influenced by external pressures applied to operators (e.g., evaluation requirements, training material, personal biases); and Path 6 shows that reported maintenance actions are influenced by external pressures applied to maintenance personnel (e.g., fear of repeat write-up "black marks", training material, personal biases).

It is important to understand how information is transmitted in this system and how well it is transmitted. For if this information is not being transmitted efficiently -- and there is considerable evidence that it is not -- then mission performance probably can be improved, perhaps dramatically, by simply improving the transmission efficiency of maintenance information, thus improving the efficiency of maintenance itself.

This study is a "first examination" of this problem from a systems point of view, using information theory as an analytic tool. This was a small study (one man-year), using data collected for other purposes and applying certain concepts for the first time. As a consequence of these limitations, several conclusions may be tenuous. Even so, the study does demonstrate that information theory can be used as an analytic tool for measuring certain maintenance characteristics. The results presented in this report are based upon analyses of data collected for earlier reliability and maintainability studies, and not upon data collected specifically for the purpose of information analysis.

1
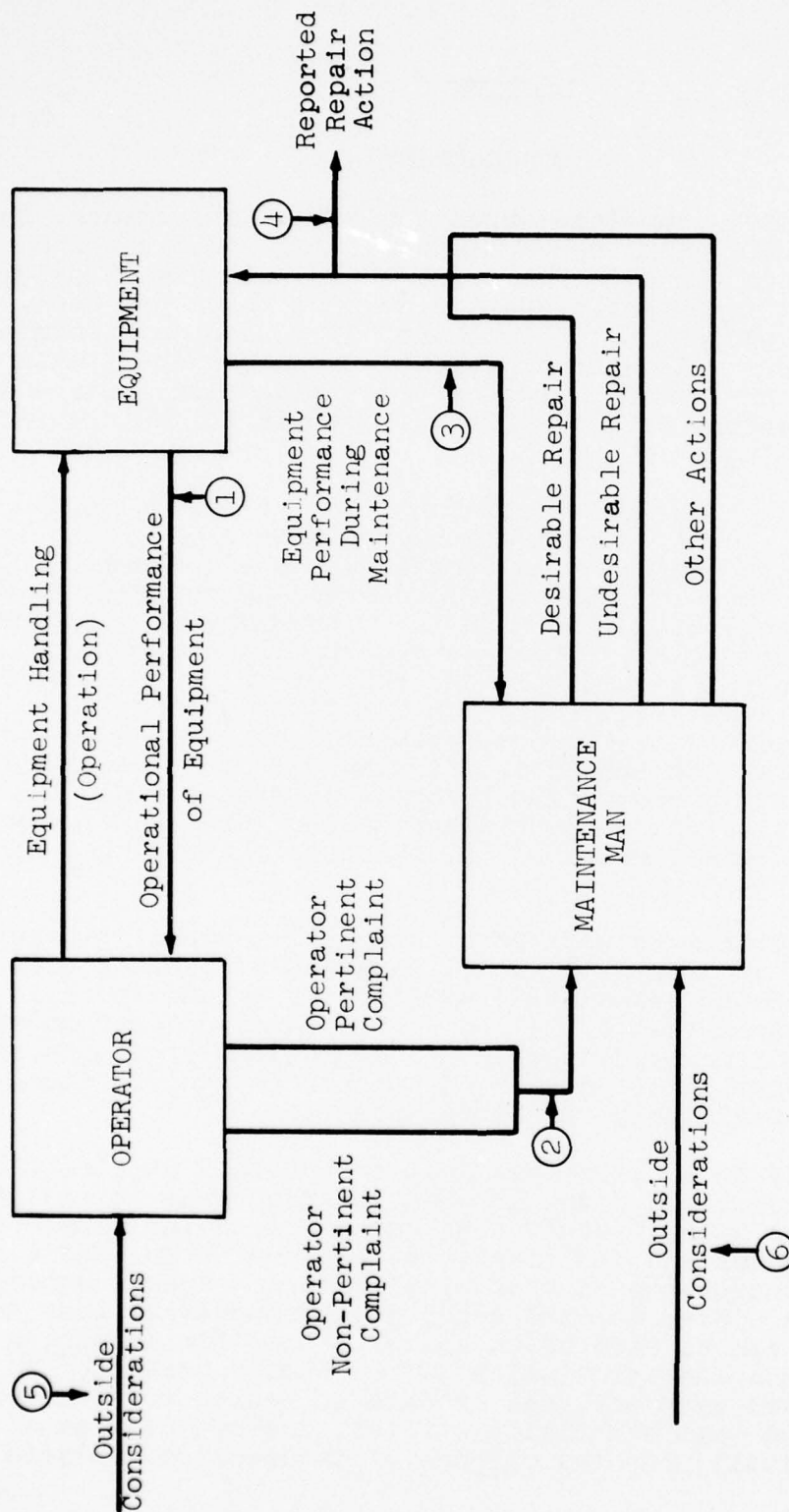
FIGURE 1

MAINTENANCE/PERFORMANCE INFORMATION CHANNELS
FROM A MAINTENANCE ANALYST'S POINT OF VIEW

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1. BACKGROUND

For several years, many agencies and investigators have studied facets of the problems displayed in Figure 1. At ARINC Research Corporation, where the present research effort was performed, these studies were primarily directed at Paths 1, 3, and 4. Concern was with how equipment malfunctions are displayed to operators (Path 1), with the effectiveness of ground test equipment (Path 3), and with the reliability and maintainability of operational systems (Path 4).

For the first path, a theoretical model was developed which predicted the displayed symptoms as a result of specified degradation of equipment components (ref. 1). The procedures developed allowed for the preparation of symptom/cause tables (thus the name "The Symptom Matrix") like that illustrated in Table 1. These tables can be developed either (a) from early design stage engineering information, or (b) from operational failure and repair information. The tables can be used to determine the need for improved troubleshooting tools, strategies, and documentation and assist in the maintenance and improvement of required personnel skills. If the symptom matrix is produced during system design, it can be used as a design tool for making recommendations concerning packaging, the location and number of test points, and the type and output of "front-panel indicators." At the same time it can be used to anticipate tools, spares, training, and training aid requirements.

For the third path, attention was directed toward (a) the adequacy of ground test equipment to verify "in-flight" symptoms, (b) the ability of test equipment in general to reject "bad" components and accept "good" components, and (c) the cost effectiveness of automatic test equipment. These studies were always hardware oriented and always system specific.

Attention given to the fourth path dealt with how much confidence maintenance data analysts could place on reported maintenance data. If these data are to be used as an information source for reliability and maintainability evaluation and improvement studies, they must be reasonably accurate and relatively complete. Independent checking of AFM 66-1* data led to the conclusion that for purposes of detailed evaluation information, these data were not adequate (ref. 2). Coverage was good, but details were missing and accuracy was low.

Although these studies flirted with it, none directly attacked the problem of personal bias in data reporting or personnel effects upon system effectiveness. If Channel 1 is

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*"Maintenance Management: Organizational, Field and Depot", 15 June 1966.

TABLE 1

SYMPTOM MATRIX FOR AIRBORNE BOMBING/NAVIGATION SYSTEM

Symptom	P_S	Units Which Could Cause the Symptom	P_B	Failures per 10^6 Hours	P_A
No Range Marks	0.00504	Video Amplifier	0.600	1,054	0.41
		Range Mark Generator	0.165	352	0.34
		Range Mark Generator Power Supply	0.145	135	0.78
		Marker Mixing Gate Amplifier	0.035	78	0.32
		Cabling	0.032	24	0.95
		Circuit Breaker, Fuses, Relay	0.010	8	0.86
		Oscilloscope	0.008	75	0.08
		Oscilloscope Power Supply	0.004	121	0.02
		Other	0.0003	3	0.005
		. . . .			
Wavy Range Marks	0.00188	Video Amplifier	0.740	1,054	0.17
		Range Mark Generator	0.160	352	0.11
		Range Mark Generator Power Supply	0.054	135	0.10
		Marker Mixing Gate Amplifier	0.046	78	0.15
		Other	0	2	0.005
		. . . .			
No Sweep on Oscilloscopes 04 and 09	0.00218	Sweep Generator	0.993	328	0.95
		Power Supplies (for both Oscilloscopes)	0.007	36	0.05
		Other	0	15	0.005

P_S = Probability of the symptom occurrence

P_B = Probability of unit failure given symptom

P_A = Probability of the symptom, given that the unit has failed

operating perfectly, i.e., if the system is designed so that it unambiguously displays symptoms so that each distinct symptom is related to exactly one discrete maintenance action, then it is still possible for the operator (Channel 2) to misread or mis-report symptoms and to mislead the maintenance man. (If the test equipment is effective, Channel 3, the misleading nature of this information can be determined quickly and unequivocally. If the maintenance man does the right things, then on the next mission the equipment should perform properly and the maintenance man's report (Channel 4) should accurately indicate what malfunction had occurred.

Careful, cyclical review of the channels of information flow shown in Figure 1 will indicate that if the test equipment in the system (Channel 3) performs satisfactorily, then the operator is more or less irrelevant from a maintenance point of view. However, reflection on the status of current and proposed test equipment designs indicates (a) that satisfactory test equipment diagnosis, independent of mission performance information, is not to be expected, and (b) even perfect test equipment is a poor alternative to adequate failure reporting -- why waste time replicating adequate operator malfunction reports? The problem is one of finding out who and what to "trust" with respect to how the system is or has been performing. If this can be accomplished effectively, test equipment need only be used for those situations where ambiguity remains, or -- ideally -- at the next level of repair needing information beyond that contained in the symptoms.

2. PURPOSE

This research was designed to analyze a representative sample of Air Force failure reports and the resulting set of maintenance actions, to identify possible relationships between the information content of the reported symptoms in these failure reports and maintenance efficiency. In addition to describing the above relationships, (the study was intended to) we hoped to establish the feasibility of trying to improve maintenance efficiency through manipulation of failure report content.

Initially, the effort was viewed as exploratory and was primarily directed toward the first of the two issues cited above (identifying relationships between failures reports and maintenance results). The study would be considered a success if it objectively evaluated the feasibility of information theory as a maintenance data analysis tool. Heretofore, published maintenance analyses contained tantalizing suggestions that information theory could be applied to maintenance data, but these studies had not directly approached the issue. Therefore, the activities initially planned for this study included, in sequence:

(1) Given a representative sample of Air Force failure reports, attempt to measure the amount of information communicated to the maintenance man by the equipment operator.

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(2) If this is successful, describe how the linguistic content of these failure reports is related to the maintenance man's malfunction diagnosis.

(3) Develop some general conclusions on how to improve maintenance efficiency through manipulation of the failure reporting process.

Later, as the results of this investigation began to take form, the areas of interest were expanded to take advantage of some additional data which had become available. These data, and the analysis which had already been accomplished, made it clear that there was much more to information theory as a maintenance analysis tool than had been anticipated and that changes in maintenance reporting procedures were not the only factors that could appreciably affect maintenance efficiency.

Accordingly, the study was expanded to include the following additional activities:

(4) Evaluate the potential of information theory as a general tool for identifying the structure* of maintenance data.

(5) Develop some recommendations on how to improve system efficiency through manipulation of the total failure reporting and maintenance process.

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*"Structure" here is a technical word meaning, roughly, how the elements being studied fit together and how they are mutually related -- see Reference 3.

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SECTION II

DATA

The data used in this study were collected for two previous and unrelated programs with other purposes in mind. Since the analyses (and their interpretations) depend upon the specific nature of this data, an understanding of its background and nature is essential for an understanding of this report.

1. WALKER AIR FORCE BASE

Data collection for an Air Force reliability assessment and improvement program began in March 1957 and continued until July 1963. Between March 1960 and April 1961, data were collected on all maintenance activity on the ASB-4 Bombing/Navigation systems installed in one wing of B-52 aircraft at Walker Air Force Base.

ARINC Research field engineers obtained this data from debriefing interviews with flight line maintenance personnel immediately after the latter returned from a maintenance action at the aircraft. A complete incremented time history of each event was recorded, accounting for all elapsed time from receipt of the work order to completion of repair. Details of actions taken, units involved, and the circumstances encountered were also recorded. In addition, the symptoms which initiated the maintenance actions were recorded verbatim, in narrative form.

Any hesitancy which the maintenance men may have had toward reporting possible uneconomical usage of time was minimized (hopefully) by the excellent rapport established between them and the ARINC Research personnel, and their assurance from the base commander that details of the raw data were available only to ARINC Research.

The validity of the data obtained was checked by informally comparing it with a control sample of data obtained by direct observation of several maintenance events at the aircraft. No significant difference was found between the data samples obtained using the two collection methods.

Appendix I shows all the variables considered in the data collection at Walker AFB during the period March 1960 to April 1961.* There were 1722 reports involving the ASB/4

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*The data collected during this period differ from those of the total data collection period in two respects. These cover all maintenance action on the aircraft and systems under observation and these also include the verbatim malfunction report - the "symptom."

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bombing-navigation system. These reports were abstracted and used as the primary data for this study. A "working" IBM card format was devised for these reports; the format included the data elements listed in Table 2.

TABLE 2

ASB/4 FLIGHT LINE DATA
USED IN THIS STUDY

Variable - Code Explained In:	Appendix Number	Item Number
1. Aircraft Identification	I	1
2. Report Number	I	26
3. Grammatically Coded Symptom	IV	--
4. Number of Phrases in the Symptom	IV	--
5. Whether or not the Symptom was Verified	I	29
6. The Units Involved in the Action	I	12
7. Numbers and Skill Levels of Maintenance Men Involved	I	30
8. Maintenance Time Variables	I	31, 35 & 40

For some reports, information is available concerning the identity of the personnel involved in the maintenance action, as well as personal information (test scores, IQs, etc.) for these men. Sample sizes and problems associated with defining equivalent tasks and skills made analysis of these items unfruitful. Perhaps with further attention they can be led to produce interesting results.

2. DOVER AND SELFRIDGE AIR FORCE BASES

Data collection for an Air Force reliability and maintainability improvement program for F-106 electronic subsystems was begun in May 1964 and is still in process. Between November 1965 and February 1966, data were collected on all maintenance activity on the avionics subsystems installed in the F-106 aircraft at Selfridge and Dover Air Force Bases.

The data were obtained from Air Force maintenance records (Forms AF 76-3, AFTO 210, and AFTO 211) and were supplemented with individual follow-up by a field engineer. A complete repair history of each event was recorded, accounting for the identity of the operational and maintenance personnel, the operational symptoms (ADC 66-28 Codes), and the flight line diagnosis, the symptom reported to the shop (verbatim report; the flight line "How Mal" code was not analyzed) and the shop repair action,

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and the system performance on the next mission. These data include 1809 flight line maintenance actions (collected at both bases) and 407 shop maintenance actions (collected at Dover AFB only).

Since the data were generally drawn from Air Force records, filled out by Air Force maintenance personnel as part of their daily routine, any errors or misinformation which might be present in Air Force maintenance paper work are also reflected in these data. As it happens, in a later section of this report, this opportunity for bias will be shown to have some alarming implications with respect to system performance.

Appendix II shows all of the variables which were considered in the data collection at Dover and Selfridge AFBs. There are 1268 flight line reports from Selfridge and 541 flight line reports from Dover. All of these reports concern malfunctions of the electronic subsystems in F-106 aircraft. "Working" IBM card formats were devised for these data. Table 3 presents the F-106 flight line maintenance data elements studied here. Table 4 performs the same function for the shop data.

3. SYMPTOMS

The subject of this research is symptoms, and their ability to guide maintenance. But since very little is known about this problem, it seems appropriate to give a little attention to at least two major issues: (1) how symptoms are reported and (2) how reported symptoms can be coded for analysis. The details of these two issues are given in Appendices III and IV, respectively.

3.1 Symptom Reporting

Symptom reporting is a matter of some concern because (a) an objective of the study is to improve the process, and (b) the primary symptom data were collected on the ASB/4 nearly five years before this analysis began. At the outset of this study, there was some question about these data still representing Air Force maintenance practice.

The detailed material in Appendix III indicates that symptom reporting procedures at the various Air Force bases sampled are similar in most respects, whether they are SAC bases or TAC bases, and whether the symptom reporting process was observed in 1959 or 1966. All of the bases use the debriefing procedure outlined in AFM 66-1, and in general, the "operator - debriefer - maintenance control - supervisor - flight line personnel" chain mentioned in AFM 66-1 was also used both then and now. The biggest consistent difference seems to be whether or not flight line maintenance personnel routinely have direct (or semidirect) contact with system operators prior to debriefing. There are

TABLE 3

F-106 FLIGHT LINE DATA
USED IN THIS STUDY

Variable - Code Explained In:	Appendix Number	Item Number
1. Base	II	1
2. Aircraft Identification	II	4
3. Date of Maintenance	II	6
4. Pilot's Identification Code	II	3
5. Symptom Code	II & III	16
6. Malfunction Verification	II	19
7. Maintenance Supervisor's Identification Code	II	36
8. Maintenance Assistant's Identification Code	II	37
9. Unit Involved in the Action	II	25
10. Action Taken	II	20
11. Troubleshooting Method	II	22
12. Maintenance Concept (Team Approach)	II	21
13. Whether the Equipment Operated Successfully on the Next Flight	II	23
14. Total Subsystem Downtime	II	24
15. Pilot's Rating of Equipment Status	II	9
16. ARINC Research Rating of Equipment Status	II	18

TABLE 4

F-106 SHOP DATA USED
IN THIS STUDY

Variable -- Code Explained In:	Appendix Number	Item Number
1. Flight Line Maintenance Personnel Identification	II	36 & 37
2. Sympton Reported to the Flight Line	II & III	16
3. Whether or not the Flight Line Malfunction was Verified	II	19
4. Whether the Equipment Operated Successfully on the Next Mission Following Flight Line Maintenance	II	23
5. Unit Serial Number Removed at the Flight Line	II	27
6. Symptom Reported to Shop by the Flight Line Maintenance Crew	IV	--
7. Diagnosis of Unit Condition	II	33
8. Test Procedure Used	II	34
9. Repair Action Taken for Unit	II	33

undoubtedly other differences in procedures between bases, but these do not seem to be greater than differences which exist __within__ bases from time to time - depending upon circumstances.

Because of the overall similarity in symptom reporting methods, and the general inconsistency or unspecifiability, or both, of the differences, it seems safe to assume that the data analyzed in this study are as representative of current procedures as is possible. Generalizations from results obtained from these data analyses are probably as safe (or unsafe) as they would be from data collected at any other base.

3.2 Symptom Coding

Symptom coding is a matter of some concern because of a problem one always has in coding data: How much of the uniqueness of this observation is irrelevant to the issue at hand?

The detailed material in Appendix IV indicates how this problem was solved for this study. In general, each ASB/4 symptom was taken as a verbatim language specimen. It was parsed (i.e., broken down grammatically) into four major categories: subject, verb phrase, subject modifiers, and modifying (or qualifying) words and phrases. After analyzing each symptom in this manner, the symptom components were each assigned a four-digit code. The codes were assigned in such a way that all grammatically (and semantically) distinct word patterns are numerically distinct, but degrees of grammatical similarity are represented by similar degrees of numerical similarity.

This coding system, which may be viewed as an experiment itself, worked quite well, and can be recommended, with some improvements, to maintenance data processors and personnel interested in research using repeated samples of verbal material as dependent variables.

SECTION III

METHODOLOGY

The "increasing complexity of modern military systems" has been mentioned so often it is nearly cliche, but a recognition of "the complexity problem" demands not only increasing attention be given to the role of man in the system, it also demands improved and increasingly responsive techniques for quantifying his performance in this role. The present study, as part of an effort to satisfy a portion of this need, posits two procedures which should help satisfy this demand. The first is information theory as it is employed in this report; the second is the enumeration of alternative criteria for evaluating maintenance. These two procedures, as they affect the present study, are discussed below. The third section below describes the general computer analyses prepared for this study.

1. Information Theory

Information theory, a relatively new development in mathematics, has been receiving considerable attention in behavioral research over the past decade because of its ability to handle qualitative data. Its application in the context of maintenance reporting is new, and this section of the report is intended to provide a brief overview of information theory -- what it means and how it is applied.

It is not the purpose of this section to derive the foundations of information theory, nor to expound on its rationale. These topics have been adequately discussed elsewhere (refs. 3 and 4). The purpose here is to give those readers who are not familiar with this mathematical technique a frame of reference for evaluating the significance of analyses using information concepts.

1.1 Fundamentals

To gain "information," in the ordinary sense of that word, means that something must be learned which was not previously known. In its technical sense, information means much the same thing. In order to learn something new about an item or event, one must first have some degree of ignorance concerning that item or event. In the mathematics of information theory, this ignorance is labled as uncertainty, and it is defined as the amount of information which could be obtained. The amount of information obtained is dependent upon the amount of uncertainty which previously existed: the more uncertainty one has (the greater the state of his ignorance about something) the more his uncertainty can be reduced (the more he can be enlightened.)

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Now, the mathematics of information theory make it possible to measure the amount of uncertainty present (provided of course that certain suitable conditions are first met.) First, it is important to see how uncertainty varies in an intuitive way, then the mathematics will be presented. If an equipment operator says to a maintenance man: "It is either the 070 unit or the 6917 circuit breaker," then the maintenance man has a fair understanding of what the problem is and his uncertainty about what has failed is rather small. On the other hand, if the operator had said: "The performance was poor," the maintenance man is in a state of ignorance, and his uncertainty about what has failed (indeed whether or not there has been a failure) is relatively high. Similar homey examples lead one to observe that uncertainty is related to how many alternatives could have occurred.

Indeed, uncertainty is related to how many alternatives could have occurred. In particular, the amount of information (H) available in an event with n <u>equally</u> likely alternatives is <u>defined</u> as the binary logarithm of n, or

$$H = \log_2 n \tag{1}$$

The choice of the base 2 is not arbitrary (ref. 5). It produces a measure which yields linear relationships when H is compared to certain dependent characteristics of human performance, such as errors in transmission or perception as a function of stimulus and response complexity. Because information is measured on a logarithm to the base 2 it is expressed in units called "bits" (from binary information unit).

One can think of "information" as the smallest number of binary (yes-no) questions which must be asked in order to completely eliminate the uncertainty about an event. If the event has two equally likely outcomes one question will always work. For if you are right, you know what the outcome was, and if you then discover that you were wrong on your guess, you know what the outcome was anyway. If the event has four equally likely outcomes, it would take you two questions to be guaranteed of finding the answer. Your question strategy could be illustrated as follows:

Ask: (First Question)

"Was it event 1 or 2?"

If the answer is yes

Ask: (Second Question)

"Was it event 1?"

If the answer is yes, fine.

If the answer is no, then

it was obviously event 2.

or

If the answer (to the First Question) is no

Ask: (Second Question)

"Was it event 3?"

If the answer is yes, fine.

If the answer is no, then

it was obviously event 4.

In general, when all the outcomes are equally likely, the problem of number of questions is very easily solved: $\log_2 n$. However, when events are not equally likely, uncertainty is changed and information must be modified. If a coin is tossed ten times one is not surprised to learn that it was not ten heads, and if one were concerned with only the two events: (1) it was 10 heads or (2) it was not 10 heads, then one does not have very great uncertainty about the outcome. Now it is difficult to illustrate how one might ask a "small number of questions", but it is easy to quote the information theory formula which takes this situation into account:

$$H = -\sum_i P_i \log_2 P_i$$

where H is the total information in the set of outcomes.

i is a counting index for the set of outcomes of the event.

P_i is the relative probability of each outcome.

This formula yields the number of questions one would have to ask, on the average, if one used the very complicated optimum questioning order which was required by that situation. The problem of finding that order is another problem and is beyond the scope of the current treatment.

1.1.1 Univariate Analysis - An Example

When N equally likely alternatives can occur, the probability, P, of each alternative is 1/N. Hence,

$$H = \log_2 N = \log_2 1/P \qquad (3)$$

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Now, this relationship can be generalized to cases in which the alternatives are unequally likely:

$$h_1 = \log_2 1/P_1 \qquad (4)$$

where h_1 is the information associated with the occurrence

of alternative i and

P_1 is the likelihood of alternative i.

Suppose that a biased coin comes up "heads" nine times out of ten (P_1 = .90). According to this equation the information associated with a "head" on a particular toss is:

$$\log_2 1/.90 = \log_2 1.11 = .15 \text{ bits}$$

and for tails it would be

$$\log_2 1/.10 = \log_2 10 = 3.32 \text{ bits}$$

(The disparity between these numbers is in agreement with our intuitive sense of uncertainty as described above. In alignment with this is the fact that the informational value of a particular event, $h = \log_2 1/P$, is called its surprisal.)

If these two informational values are averaged in terms of their relative likelihood of occurring, the result is the information to be expected in the event:

$$H = \sum_i P_1 h_1 = \sum_i P_1 \log_2 1/P_1 \qquad (5)$$

where, again P_1 is the likelihood of the event and

h_1 is the informational value of the event.

For computational convenience this formula can be reduced to:

$$H = -\sum_i P_1 \log_2 P_1$$

If the likelihood of each event is based upon the number of times that event occurred, N_1, divided by the total number of observations, N, (that is if P_1 is based upon a finite set of observations) then

$$H = -\sum_i \frac{n_1}{N} \log_2 \frac{n_1}{N} \qquad (6)$$

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and this reduces to:

$$\log_2 N - \frac{1}{N} \sum_1 n_1 \log_2 n_1 \qquad (7)$$

Whether one uses equation (2) or equation (7) is a matter of choice and computational convenience; the result is, needless to say, the same.

Table 5 is an example of how the second formula (7) is applied, in these data, to measure the uncertainty associated with malfunction verification. Although there are eight possible alternatives, and thus 3.0 bits of possible information, there are only 1.08 bits of information actually available. This is due to the predominance of the code associated with reported verification (there is very little surprisal associated with the discovery that a particular malfunction was verified).

These two calculations can be related by yet another formula to indicate the amount of information already available, I_s*(that is information given by knowing that the sample has unequally occurring alternatives):

$$I_S = U_T - U_S \qquad (8)$$

where I_S = the information given by knowledge of the sample

U_T = the maximum possible information in this context

U_S = the uncertainty calculated for the set of outcomes which could have occurred.

1.1.2 Bivariate Analysis - An Example

The preceding paragraph set the stage for measuring the amount of information given by a particular symptom (the difference between what was known before the symptom was reported, U_T, and what was left to be found out, U_S - see section IV, paragraph 1). But it also set the stage for considering

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*The reader need not be alarmed by this shift from H to U and I, the quantities are numerically equivalent, only the point of view is changed. H traditionally refers to information in general; U refers to uncertainty or information to be found out; I is introduced for reader convenience as the corresponding term for information already found out.

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TABLE 5

EXAMPLE OF INFORMATION (UNCERTAINTY) CALCULATION, MALFUNCTION VERIFICATION

Code	Number of Occurrences	P_1	Uncertainty (U) = $P_1 \text{ Log}_2 P_1$
Blank	1.	.00055	.00598
1	1428	.78939	.26933
2	0	---	---
3	31	.01714	.100556
4	199	.11000	.35028
5	0	---	---
6	31	.01714	.100556
9	119	.06578	.25826
Total	1809	1.00000	1.08496

Verification Codes:

1. Specific operator complaint verified.

2. Specific operator complaint not verified. Other trouble found in same subsystem.

3. Specific operator complaint not verified. Trouble found in related or associated subsystems.

4. Maintenance originated complaint.

5. Not checked.

6. Advance base operation. No repair data available.

9. No trouble found.

bivariate constraint -- the situation where knowledge concerning one variable can be "converted" into partial knowledge concerning a second. This is very much like <u>correlation</u> between quantified variables. In fact, this is so much like correlation between quantified variables that its application to qualitative material has been something like a breakthrough in the state-of-the-art of performance measurement.

Information theory can be used to measure the amount of knowledge to be gained about an event of concern by learning about a collateral event. Thus it can be used to "predict" eye color, given hair color or to predict the trouble shooting procedure to be tried, given the symptom which was reported. Clearly, it is applications like the latter which make information theory so inviting in the present context.

In a bivariate analysis one considers the two variables under observation (say A and B) as separate characteristics of one compound event. (e.g. to compare gender to eye color one simply thinks of the set of possible observations: blue-eyed girl, brown-eyed girl, green-eyed girl, ... , blue-eyed boy, brown-eyed boy, green-eyed boy, ...) The information in this event is calculated as before, using either equation (2) or (7), and the result is called the joint uncertainty, $U_{A\&B}$. If this measure is compared to U_A, the uncertainty in variable A, <u>plus</u> U_B, the uncertainty in variable B, the result is an assessment of the degree of overlap between these two variables.

$$U_{S:P} = U_S + U_P - U_{S\&P} \tag{9}$$

where $U_{S:P}$ = the amount of uncertainty about S which remains given knowledge of P. (the constraint)

U_S = the a priori amount of uncertainty associated with variable S.

U_P = the a priori amount of uncertainty associated with variable P.

$U_{S\&P}$ = the amount of uncertainty associated with the compound event (S&P)

Figure 2 represents the application of equation (9) to F-106 data corresponding to pilot and symptom. The degree of constraint is 2.42205 bits of information. Unfortunately, this example is not simple. When comparing the extent to which a pair of variables overlap, the amount of joint information ($U_{A\&B}$) must be compared to the total amount of information possible. This latter is limited by both the sample size (the number of
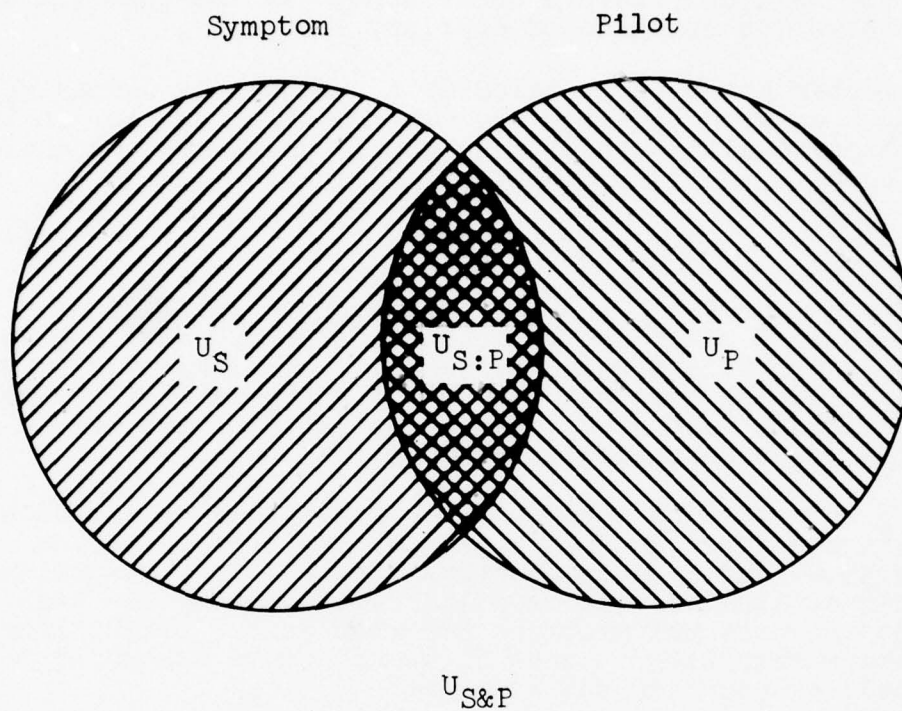
18

Symptom   Pilot

U_S $U_{S:P}$ U_P

$U_{S\&P}$

U_S (Area ⊘) = 5.29164

U_P (Area ⊗) = 6.10230

$U_{S\&P}$ (Area ⬭) = 8.97189

$U_{S:P}$ (Area ◉) = $U_S + U_P - U_{S\&P}$ (Eq. 9)

          = 2.42205

FIGURE 2

EXAMPLE OF JOINT UNCERTAINTY CALCULATION

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different observations possible) and the sum of the separate _a priori_ uncertainties $(U_A + U_B)$. In the present sample, there are only 1809 observations; thus U_T (or U_{max}) is less than or equal to $Log_2(1809) = 10.8$. Adjusting $U_{S:P}$ to compensate for this lower maximum possible uncertainty yields what seems to be a conservative estimate of overlap, 1.80 bits.

No matter how $U_{A:B}$ is calculated, whether by comparison with $\log_2 N$ or with $U_A + U_B$, the fact remains that it, in turn can be compared with both U_A and U_B. If one draws the quotient of $U_{A:B}$ to U_B,

$$C_{A:B} = \frac{U_{A:B}}{U_B} \qquad (10)$$

he obtains a measure of the percentage of variability of characteristic B which can be accounted for by relationship to variable A:B. This term, C_A:B, is very much like r^2 for product moment correlation and that accounts for the possibility of using the square root of $C_{A:B}$ as an estimate of the degree of correlation between variables A and B (ref. 6).

$C_{A:B}$ is read "The constraint of variable A by variable B." In the example given in Figure 2 pilot constrains symptom, $C_{S:P}$, by 35.8% and symptom constrains pilot, $C_{P:S}$, by 29.5%. The former constraint, the more interesting, suggests that, for F-106 avionics malfunctions reported at the flight line, 36% of the variability in _what_ is wrong can be accounted for (predicted) by _who_ flew the airplane!

1.2 Applications

In the present study, information theory is applied in two ways. First, as a univariate calculation: here, for example, one counts the number of times each particular type of "black box" is handled in connection with a certain symptom*. The information contained in the distribution of occurrences for these black boxes is then calculated. If this information decreases when words are added to the symptom in question, then the additional words reduced the uncertainty concerning which "black box" is the bad one. That is to say, the additional words convey information. In particular they convey exactly the _amount_ of information by which the uncertainty changed.

*Symptom here must mean a _set_ of observations: otherwise there is no distribution of units to count. The set is defined in terms of reported words or word patterns which are the same, or which appear to be the same. As it happens, the change of information as the definition of sameness changes, is taken as a measure of sameness.

The second application of information theory is in bivariate analysis. Here, information theory is used as a technique for correlating qualitative data. Each of the variables in question is considered as being a set of observations sampled from a large population with a finite number of different states. (An observed data point could be any one of a finite number of "readings".) The uncertainty in the distribution of these states is calculated for each variable separately. When the sum of these uncertainties is compared to the uncertainty calculated for the compound event, (the variables in question being taken as a pair) a measure of the degree to which either variable constrains the other is obtained.

Information theory is a relatively recent mathematical development and the meaning of its "sampling distribution" is not yet defined. As a result, there is no direct statistical method for evaluating statistical significance. In the present study, since concern is with "practical" rather than "statistical" significance, this is not particularly disarming. However, it would be nice to have a procedure for evaluating the chance likelihood associated with any particular observation.

In order to estimate the sampling distribution for univariate analysis of the ASB/4 data, a number of random samples of data were selected and the univariate uncertainties were calculated. Figure 3 plots the observed mean of these calculations as a function of sample size. Figure 3 also includes the maximum possible information ($\log_2 N$) and the observed 10th percentile values. Once a specified sample of data is described,* its uncertainty can be compared to that indicated by the Figure for samples of equivalent size. (The calculated values on this Figure are probably spuriously low because random samples from the ASB/4 data include a large number of preventive maintenance actions. These actions are not associated with "black box" activity, and thus the particular black box "no unit removed" is a likely observation. This being so, Figure 3 is probably a conservative test when used to evaluate information transmission in operator malfunction reports.)

In order to determine the statistical unlikelihood of a bivariate calculation, an "efficiency measure" of bivariate constraint was defined. This measure attempts to assess the usefulness of a given amount of bivariate constraint. For example, if there are 1024 observations of two variables, there is a possible uncertainty of 10 bits. If one variable has

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*A sample of data now becomes a set of observations hypothesized to be repeated reports of a single symptom.

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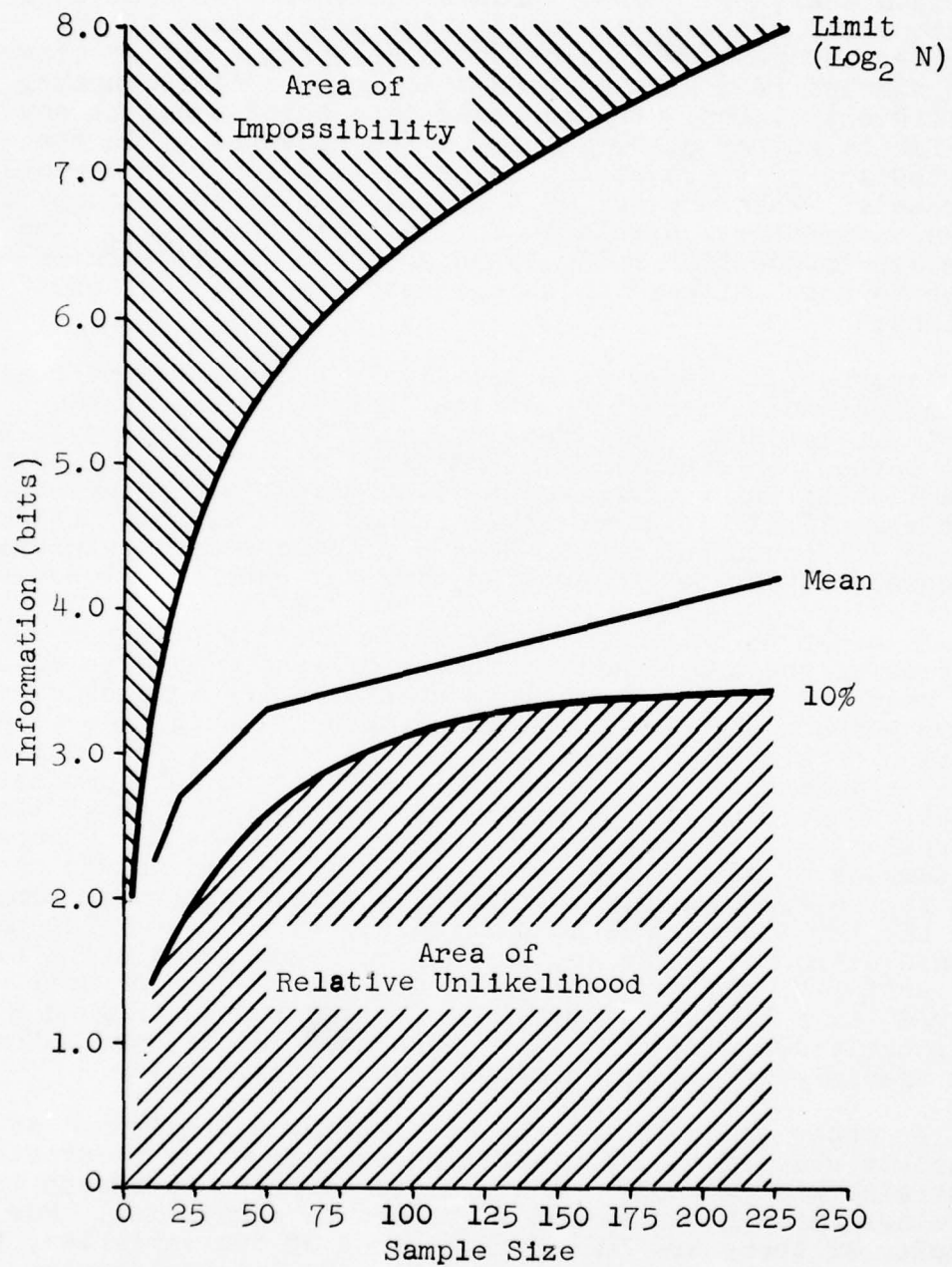
FIGURE 3

MEAN INFORMATION IN
RANDOM SAMPLES OF ASB-4 DATA

6 bits by itself, a second has 3 bits by itself, and if the joint event has 8 bits of information, then the first event constrains the second event by one bit (6+3 - 8) or 33% (one bit of constraint divided by the three bits in the constrained variable). This is an efficiency of 16.6% (one bit of constraint divided by the six bits in the constraing variable.) If all of the data (10 bits) were used to predict the second variable (all of the variable's uncertainty is always predictable *from* all of the observations), the efficiency would be 30% (three bits of constraint divided by ten bits of observation.) Where we predicted one bit using six bits, the observed constraint (of 33%) is not really very impressive, in spite of its absolute size, because it predicts with less efficiency than could be achieved by using all the data. Somehow it seems that a good prediction could do "better" than this sort of an average. (This is not a rigorous concept and has been offered only as a tentative method of evaluating the efficiency of observed bivariate constraint.)

2. MEASURES OF MAINTENANCE EFFICIENCY

Maintenance efficiency can be measured in a variety of ways. And if concern is really with the efficiency of maintenance, then all reasonable measures should be explored and compared The present study uses five criteria. The first, the most familiar criterion - maintenance time, is subdivided into seven categories: (See Table 2 item 8 and Table 3 item 14)

1. Preparation (Prep.) Time   The clock hours necessary for the maintenance man to get ready to work on the system, to check paper records, to obtain tools, to warm up equipment, etc.

2. Malfunction Verification (MV) Time   The clock hours necessary for the maintenance man to verify that the system has indeed failed in a manner consistent with the reported symptom.

3. Fault Location (F.L.) Time   The clock hours necessary for the maintenance man to locate the malfunctioning black box.

4. Part Procurement (P.P.) Time   The clock hours necessary for the maintenance man to obtain the necessary replacement units.

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5. Repair (Rep.) Time — The clock hours necessary for the maintenance man to physically repair the system, remove and replace units, adjust units, check out the final repair, etc.

6. Malfunction Administrative Delays (Malf. Ad.) Time — The clock hours necessary for the maintenance man to perform other duties, e.g., lunch, coffee, another job, sick call, etc.

7. Total Subsystem Down Time — The total clock hours the system was out of service.

A second familiar criterion is the probability of malfunction verification. An unverified malfunction is bad, for if the system has really malfunctioned, failed equipment is put into service as though it were good. On the other hand, if the system has not really malfunctioned, then maintenance personnel have wasted their time (and perhaps introduced failures*) and the system has needlessly been out of use. (See Table 2, item 5, and Table 3, item 6).

The third criterion is analogous to the second. It involves verification in the shop rather than on the flight line and is related to wasted effort at the shop level. "Bench Check OK" is the probability that a black box which a flight line technician has pulled from an aircraft during repair will check as operating satisfactorily when tested by shop maintenance personnel. (See Table 4, item 7.)

The fourth criterion used here is next flight success. Was the equipment (here the F-106 avionics) successfully utilized on its next attempted mission? This is not only a measure of maintenance, it surely includes a component of operator efficiency. (See Table 3, item 13.)

The final criterion is the amount of information transmitted by reported symptoms. If one man says more in his symptoms than another man, he is clearly reporting more efficiently. (See Section III, paragraph 1.2).

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*A recent study of B-58 maintenance data suggests that reliability of good equipment can be reduced up to 20% when it is maintained unnecessarily (ref. 7).

3. DATA PROCESSING

As is becoming common, most of the calculations required for this study were accomplished by computer. Three programs (See Appendix V) were prepared for the on-site IBM 1401.

The first program calculated the uncertainty in black boxes mentioned in "little decks" of ASB/4 data. The original data, as coded and punched, was sorted (according to any sensible criterion) into piles of cards, or "symptoms." These little decks were separated by blank cards and run through the machine one after another. The program yielded an uncertainty measure for each little deck and an unweighted average for the whole set.

The second program used the same input as the first program, but treated the problem as a simple randomized design analysis of variance for each of the six categories of time and also for the number of men in each of the three (3, 5, & 7) skill levels. (Skill level and numbers of personnel at a skill level was included in the analysis as an exploratory variable. It is not certain whether these variables function as criteria of, or are dependent upon, job complexity.)

The third program was similar in intent to the first, but more general. It was used in two separate machine passes for calculating bivariate information. Here the data cards are sorted (alpha-numberic fields) on any pair of dimensions. (The dimensions can be any two sets of data columns located anywhere on the data card -- the only limitation is that subsequent machine comparison of observations was limited to two sets of five consecutive fields. Careful sorting can allow these fields to be adequate for multivariate analysis of three, four, or even five variables.) This sorting operation amounts to converting the data into an ordered comparison matrix, one observation at a time. The Phase I program accepted these cards, and a header card containing a description of the card fields to be compared, and produced as punched output an ordered comparison matrix, one cell at a time. The Phase I program also counted the number of non-empty data cells and punched this number. Phase II accepted the output of Phase I as input. This phase calculated the uncertainty of one of the variables under investigation (the uncertainty in the column sums of the data matrix) and also the uncertainty of the two variables combined (the uncertainty of the cell sums of the data matrix). To obtain the uncertainty associated with the second variable being studies, a second application of the Phase II program was required. Properly planned, this second application could be in conjunction with another variable, and an additional combined uncertainty could be obtained. In this manner it is possible to study the total mutual structure of three variables in three passes of the Phase II program.

SECTION IV

ANALYSIS

The subsections of this section present the results of the various analyses conducted during this study. The subsections parallel the analyses themselves, which attended to three separate issues:

(1) Where is the information contained in symptoms?

(2) What can be predicted from symptom content?

(3) Can information theory be applied to maintenance data in general?

1.   INFORMATION IN SYMPTOMS

The fundamental assumption here, and indeed the fundamental assumption behind malfunction reporting in any context, is that symptoms contain information. They say what is wrong, which "thing has busted." They direct behavior. While it is necessary to check that assumption, it is also a purpose of this study to know what part(s) of the symptom are useful.

To prove this assumption is trivial: maintenance people don't do maintenance without a symptom, therefore the occurrence of a symptom is an excellent predictor of the occurrence of a maintenance action. To measure the amount of information in a symptom is not trivial. This is the primary subject of the following paragraphs.

1.1 A Bench Mark

Before the amount of information given by a particular symptom can be calculated, how much information could have been given must be known. Then the amount which was given is merely the difference between what could have been given and how much had to be found out by troubleshooting. In notation, this is simply:

$$U_t = I_s + U_s \text{ or } I_s = U_t - U_s$$

where

U_t = the total uncertainty in the system (see below)

I_s = the information contained in the symptom (the information given to the maintenance man) and

U_s = the uncertainty remaining in the symptom (the uncertainty contained in the distribution of the units handled in the set of maintenance actions used to define the symptom).

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The ASB/4 has 146 flight line replaceable units. Thus, there are 147 black boxes which a technican can remove on a given maintenance action (including the black box "remove nothing"). Accordingly, there is a total of 7.20 bits (Log_2 147) of uncertainty possible concerning which black box was removed on any particular maintenance action. When the relative failure rates* of the boxes in the ASB/4 ($\Sigma p \log p$) are considered, the uncertainty as to which particular black box was removed on a particular maintenance event is only 5.93 bits.

This latter number can serve as U_t - the bench mark for subsequent calculations. If a symptom, as defined in a particular case, yields a distribution of units maintained with an uncertainty of less than 5.93 bits, then the difference in uncertainties is the measure of the information in that symptom.

1.2 An Assumption

The number calculated above is probably a reasonable estimate of uncertainty in this context, but the reader must be warned that the following calculations assume that removal rates are equivalent to failure rates. (If this is a bad assumption the results of this study will err on the conservative side!)** In the utility

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* The "relative failure rate" of the box "remove nothing" is the relative likelihood of removing nothing. (It may be of passing interest to note that 22 of the 146 removeable units did not fail during the data collection period.

** The reason for this is not simple. In the first place, analysis of removal rates and shop check OK rates indicates that for at least the F-106 flight line maintenance men, removal rates tend to be correlated to failure rates and to exceed failure rates by an amount proportional to the failure rate. That is, these maintenance men seem to be removing units too often but in proportion to the failure rates. Thus an uncertainty calculated for removal rates would be nearly the same as an uncertainty calculated for failure rates. In the second place, if removal rates were not correlated to failure rates, then maintenance men would probably be troubleshooting to optimize efficiency, that is they would always remove the unit most likely to cause the symptom; and only if that failed to clear up the symptom would they remove another unit. This would produce an uncertainty calculated on removal rates which was less than the uncertainty based on failure rates. (The latter being what the symptom really communicates.) Now, if U_s is deflated, then I_s is inflated and subsequent efforts to increase I_s by adding elements to the symptom are handicapped. Anything which increased this I_s would surely have increased the lower I_s derived from the higher U_s based on failure rates.

structure of peace time military maintenance, this is probably a fairly sound assumption. It is predicted by psychological probability choice theory and it is consonant with the personal opinions of many civilian maintenance analysts. It is not the way things should be, but it appears to be the way things are. (Since the F-106 data included shop follow up data, it is possible, for selected symptoms, to compare bench check okay rates versus bench check bad rates for groups of maintenance personnel over a period of several similar maintenance actions. For certain simple flight-line troubleshooting strategies it is computationally easy to predict what these relative rates ought to be in view of the real failure rates (as determined by the shop's bench check results). When this is done for real F-106 data (ref. 8), it is clear, at statistical significance levels well beyond .001, that flight line personnel are minimizing neither system down time nor shop maintenance time. Unfortunately, it was not computationally feasible to predict what these relative rates would be for maintenance personnel who matched removal rates to failure rates. However, the fact that maintenance men are not using the rational optimum trouble-shooting strategies, does tend to increase the credibility of the postulated suboptimum procedure.)

1.3 The Number of Phrases

Perhaps the easiest thing to measure about a verbal description is its length, and it's an obvious question to wonder what effect the number of phrases in a symptom might have upon maintenance behaviors. When an operator says more, does he really communicate more?

Table 6 shows the amount of uncertainty (U_s) associated with the number of phrases per symptom for ASB/4 flight line symptoms. Two and three phrase symptoms are more uncertain concerning which unit is removed than one phrase symptoms. There are two primary reasons for this: The first is that the one-phrase symptoms contain a much larger percentage of periodic maintenance symptoms than the multiphrase symptoms. Since periodic maintenance symptoms have a very low uncertainty (i.e. are associated with a very small number of units) this tends to change the unit frequency distribution of the one-phrase symptoms, and thus it lowers the uncertainty. A second reason is that the probability of malfunction verification increases with the number of phrases in a symptom (See Table 7). Since unverified symptoms usually have no removed units associated with them, and since "no unit" is treated as a single unit category in the information calculation, this also tends to depress the uncertainty in one-phrase symptoms. It is possible to check these assumptions by performing the information calculation without periodic maintenance symptoms or unverified symptoms. The assumptions prove to be tenable, as can be seen in Table 8.

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TABLE 6

UNIT REMOVED VERSUS
UNCERTAINTY IN NUMBER OF PHRASES
ASB/4 DATA

No. of Phrases	N	Uncertainty
1	1434	4.1118
2	222	4.7692
3	47	4.3426
4 or more	19	3.9250

TABLE 7

PROBABILITY OF MALFUNCTION VERIFICATION
AS A FUNCTION OF NUMBER OF PHRASES
ASB/4 DATA

No. of Phrases	Probability of Verification
1	.475
2	.592
3	.656
4 or more	.937

TABLE 8

UNCERTAINTY IN UNIT REMOVAL VERSUS NUMBER OF PHRASES
VERIFIED OPERATOR COMPLAINTS ONLY
ASB/4 DATA

No. of Phrases	N	U_s	I_s
1	711	5.84	.09
2	120	5.18	.75
3	28	4.01	1.92
4 or more	22	3.64	2.29

As might be expected, uncertainty is reduced (information is increased) when symptoms become longer and longer. This decrease in uncertainty suggests that increased length is functionally equivalent to increased specificity. In particular, it indicates that knowledge of how many phrases were used is equivalent to a small amount of information concerning what will be removed.

Some care must be taken in interpreting the results of analyses involving number of phrases, since an additional phrase is often a qualifying phrase indicating either an intermittency or some specificity in the occurrence of a symptom. (See below and Section IV, paragraph 1.9 for an explanation of the implications of this interpretation.)

An examination of F-106 shop symptoms shows that "bench check OK" rates go up (probability of verification goes down) as a function of the number of phrases or the number of words. (This is, of course, counter to flight line trend.) This suggests that an increase in flight line verification as a function of symptom length may be a function of a percieved rather than an actual increase in information. This may mean that the addition of phrases (or words) adds a certain amount of credibility to what otherwise might be a suspected "false alarm." This, in turn, may cause maintenance men to take corrective action in situations where they would not ordinarily do so, thus leading to higher bench check OK rates. Currently one cannot determine whether longer symptoms actually have more information as indicated by the uncertainty measure or whether this measure is an artifact of the "credibility effect" of a long symptom.

1.4 The Subject

The subject of the symptom is the central noun phrase of the verbal description given by the operator. It is not necessarily the grammatical subject (even though almost all symptoms are cast in active sentence frames.)

The amount of information given by the subject word of a symptom can be estimated by using the average U_S for all subject codes (see Appendix IV). The average uncertainty in 2-digit subjects is 2.0801 bits.* When this is compared to the bench

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* Two digit subjects are coded references to subsystems of the ASB/4. Three digit subjects were specific functional items and four digit subjects were unique word forms. The variety of three and four digit subjects made the calculation of average uncertainty over more than two digits an ill-advised estimation procedure. (The typical three digit subject occurred fewer than six times.)

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mark uncertainty, 5.93 bits, knowledge of subjects, even at the gross 2-digit level of classification, results in a substantial gain in information (3.85 bits, to be exact). The average sample size for 2-digit subjects is 53.58 cases. Comparing the obtained average uncertainty with the uncertainty obtained from random data samples of the same size (See Figure 2), it is obvious that this obtained average is lower than one might expect by chance. The obtained 2.0801 bits is lower than the random 10% value of about 2.6 bits, and considerably lower than the mean random value of about 3.3 bits. There can be no doubt that subjects convey information.

1.5 The Description

The description is the verb phrase of the symptom, when there is a verb phrase; on other occasions it is the nominalized verb, the predicate adjective, or simple adjectival form employed by the operator in his report. In the following symptoms the description is underlined.

Could not go into short range

Double VRM

Run ECM Tie In

Poor video operation 30 miles

Tg would not drive off zero

Stab Weak

Following an analysis like that in the previous paragraph, for similar reasons, the average information in 2-digit descriptions is 2.7981 bits based on an average sample size of 35.62 cases per description. This is higher than the 10% random value of 2.3 bits and quite close to the random mean of 3.0 bits for samples of this size. Thus, there is much less information in description —— no more than might be expected by chance if the data were grouped into samples of this size.

Qualitatively, there are two kinds of descriptions which appear in these data. The first kind is a technical verb or phrase (e.g. "drops out of radiate," "spoking"), which occurs relatively infrequently in the language as a whole but quite frequently here. The second kind of description is a nominalized adjective or a simple verb quite common in the language as a whole. Examples of this kind of description are verbs, such as "bad", "broken", "burned", "bent", "off", and "out". It turns out that the first kind of description occurs with certain subjects

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only, and thus is redundant ——— i.e. highly correlated with, or
constrained by, the subject. The second kind depends upon the
subject to give it meaning (in this context) and cannot convey
very much information in isolation.*

1.6 The Modifier

The modifiers are all those little fragments of detail,
qualitative and restrictive, which the operator appends to his
malfunction observations. This includes such things as when and
where the symptom was observed, what alternatives were attempted,
and how big an error was.

Modifiers do not carry a great deal of information in them-
selves (no more than chance) but their presence in conjunction
with a subject or description does effect verification rates.
(See Section IV, paragraph 2.3 below.)

1.7 The Mood

The mood of a symptom is more or less defined as the general
tone of the complaint. It seems reasonable to ask if mood is a
variable affecting information transmission. Accordingly, all
ASB/4 descriptive statements were sorted into the following three
categories:

    I.   Negative Auxiliary and Description

        Negative comment with or without additional
        remarks (e.g.: Bad, could not ___, did not ___,
        has no ___, ...)

    II. Neutral Auxiliary and Description

        Neutral comment with or without additional
        remarks (e.g.: Breaks up, came on, deflect in,
        drops out, ...)

    III. No Auxiliary or Negative Description

        One word objective statement of condition
        (e.g.: Arcs, bent, check, due, flat hits, ...)

In order to most adequately allow an opportunity for any
effect to be detected, only operator complaints were included
in this analysis. The wording of maintenance initiated

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* A bivariate analysis of subject versus description upheld these
  general conclusions.

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complaints would have a different effect upon the behavior of the maintenance man. (It doesn't make much "sense" to talk about information transmission within a maintenance man.)

The uncertainty associated with these three groups of symptoms is 4.4957; 4.4374; and 4.3969 respectively, with a total of 4.80083 for all of the data used in this test. This yields an information transmission of .3051; .3634; and .4039. These transmissions are only slightly better than zero, and are certainly of no practical significance, even though differences in transmission vary from 10 to 30%. It seems quite defensible to claim that mood has very little to do with what is being reported. Apparently there are no predominant symptoms which cause emotional involvement. Similar negative results were obtained from an analysis of the mood of the F-106 shop symptoms.

1.8 The Severity

Severity means that the operator of the equipment added something to his verbal report that maded it a stronger statement; e.g., "very", "excessive", "severe", "too much". It seemed reasonable to ask what impact this characteristic would have upon informatior transmission. The question cannot be answered simply by separating all mulfunction reports into two groups: neutral and severe. There are too many would-be neutral symptoms which could not be stated in severe terms. Accordingly a matched pairs technique was attempted. Unfortunately, there are only seven matched data points. These are not enough to analyze.

1.9 The Intermittency

By carefully sorting through the data, it is possible to define a number of symptoms containing the word "intermittent" which are matched by symptoms which are identical, except for the presence of the word intermittent. For example:

Intermittent Symptom	Stable Counterpart
Inoperative intermittently	Inoperative
Intermittently Wavy	Wavy
Intermittent Spoking	Spoking

An information analysis of these pairs —— with all of the intermittent symptoms and all of the stable symptoms grouped together to form two symptoms —— showed that the intermittent symptoms are more uncertain (contain less information) than the stable symptoms. There were 4.29 bits of uncertainty in the intermittent symptoms and 4.11 bits in the stable symptoms. This difference occured in spite of the fact that the smaller sample size (63 vs. 210) of the set of intermittent symptoms would tend

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to wash this effect out. The effect may have been due to the difference in verification rates for these two groups. Symptoms with the word "intermittent" in them have a verification rate which is considerably higher than that for the matched stable symptoms. (See paragraph 4.2.3).

1.10 The Grammatical Aspects

It seems, from the previous information, that of the grammatical elements of symptoms (Section IV, paragraphs 1.3, 1.4, 1.5, and 1.6), subjects carry most of the information in symptoms. Other functional elements (verbs and modifiers) serve to provide specificity or redundancy when used with subjects, but carry relatively little information by themselves. In the language at large, psychological studies have shown that the noun positions in sentences carry more information than verb or adjective positions. Some work has also shown that nouns constrain verbs and adjectives more than they are constrained by them. The same principles which govern the distribution of information in the English language operate here, as might be expected. There can be no doubt that symptoms do contain information and little doubt that most of the information about which black box is bad is contained in the subject. (It is sad that limited sample sizes prevented an assessment of the effect of the various ways of stating the same subject. Currently one is ill able to say what the subject really is.)

1.11 The Semantic Aspects

From the three paragraphs dealing with semantic elements (Section IV, paragraphs 1.7, 1.8, and 1.9), the connotative aspects of symptoms might appear relatively unimportant. While this is strictly true about information transmission to the maintenance man, it is NOT true about the information which maintenance personnel seem to imply is present. This will become obvious in paragraph 2.

2. PREDICTION BY SYMPTOMS

Symptoms convey information to maintenance men, and it is important to know how, or more precisely where, this information is conveyed. Of these two findings, the first justifies study of the problem of efficient failure reporting. The second finding directs attention toward fruitful areas where the efficiency of failure reporting can be improved. (Both of these issues were treated in paragraph 1 of this section).

It is equally important to know that symptoms convey information to those outside the maintenance environment: research workers, project officers, base commanders, or Air Force

systems personnel. In the previous paragraph the question was, "How can we predict black box removal rates from knowledge of the reported symptom?" Here the question is, "What else can we predict?" Since this is the case, the following information is organized around dependent variables rather than around the independent variables as done previously.

2.1 The Approach

The approach followed was almost what statisticians refer to as "fishing". A dependent variable (c.f. Section III, paragraph 2) was selected, e.g. malfunction verification, and it was explored for relationship to any independent variable (a) available in the data, and (b) reasonable in light of what is known or assumed about maintenance behavior.

In general, this meant that a large number of analyses were performed which produced nonsignificant results. These particular analyses are not reported here because they would obscure the presentation of the more positive findings. However, the observation of nonsignificant results is not considered trivial, and these analyses are not to be ignored. Appendix VI lists all the analyses conducted in the present study. The details are not given, but the list indicates what sorts of relationships were considered. (The reader may not need to be reminded that failure to observe significance is only partially correlated to absence of effect.)

2.2 Maintenance Time

Maintenance time can be separated into a number of mutually exclusive categories of activity. In the present study seven such categories were used (see Section III, paragraph 2). (Six were available for the ASB/4 data and one, total time, was available in the F-106 flight line data.)

Neither the data available nor the scope of this study allowed the application of a strong experimental design to the analysis. Maintenance time could be compared to only one aspect of a symptom at a time, but within that aspect the comparison was statistically sound. A simple randomized design analysis of variance was employed. (This allows the simultaneous comparison —— on one variable —— of groups of data of different sizes.)

Table 9 lists the significance levels of the various relationships detected. In this table the categories of symptoms labeled Mood, Description, and Intemittent are defined as before. "Repair Job" and "Check Job" refer to carefully defined subject-description pairs of frequently occurring (n≥10) corrective and preventive

maintenance requests. Table 10 contains some examples of how this was done. (Unfortunately, the computer program had not been completely debugged on the first attempt to study the effect of the Subject of the symptom and there was no opportunity to repeat the analysis.)

TABLE 9

LEVELS OF SIGNIFICANCE FOR
SYMPTOM CHARACTERISTICS VERSUS
CATEGORIES OF MAINTENANCE TIMES
ASB/4 DATA

Symptom	Maintenance Time					
	Prep.	M. V.	F. L.	P. P.	Rep.	M. Ad
Mood	.05		.05			
Description		.005				
Repair Job		.05	.05	.05	.05	
Check Job	.01	.05	.001	.001	.001	.01
Intermittant	.01		.01			
An empty cell denotes a nonsignificant result						

In the F-106 data, where symptom is coded more generally, total system down time is correlated (see Section IV, paragraph 3) to symptom. The correlation implies that 37% of the variability in total system down time can be accounted for by the symptom per se.

2.3 Malfunction Verification

In an effort to isolate the variables affecting the probability of malfunction verification, flight line ASB/4 symptoms were separated on the basis of their observed likelihood of verification. All operator complaints were classified into what seemed to be distinct jobs (see Table 10). The probability of malfunction verification was calculated for each job, and each probability was then converted into a Z score with respect to the distribution of all such probabilities. Looking only at those jobs more than one standard deviation (high and low) away from the mean probability of verification, an attempt was made to isolate the factors determining probability of malfunction verification. A very careful examination of these

TABLE 10

AN EXAMPLE OF JOB DEFINITION

Job	Symptom
1	Beacon returns Ground returns Radar returns Video returns Returns
2	FRM XX mile marker Last range mark Range marks XX mile range marks
3	AFC
4	PP counters Pres. pos. lat. PP lat. Lat. PP lat. counters Latitude Present latitude PP lat. dial
5	Memory point wind Wind(s) Doppler wind(s) North-South wind(s) East-west wind(s)

high and low verification symptoms —— including a column by column comparison of the data cards —— failed to yield any new* clues as to the causes of verification (or failure to verify).

A part of a consideration of the problem of malfunction verification concerns what happens to units after they are removed —— the bench check results. An examination of 407 F-106 shop symptoms suggests that the factors influencing "bench check OK" rates are much easier to isolate than those affecting verification. Symptoms described to the shop by the flight line maintenance crew which "bench check OK":

(1) Are more likely to contain the word "intermittent" $(p.<.01)$**

(2) Are more likely to contain a qualifying phrase $(p<.01)$

(3) Contain more words than "bench check bad" symptoms $(p<.01)$†

(4) Contain more phrases than "bench check bad" symptoms $(p<.10)$

In the light of these results, the occurrence of the word "intermittent" in a flight line symptom has a curious effect. The probability of unit removal (that is the probability of reported verification and unit action) is 98% as compared with 62% for similar symptoms without a word intermittent. This difference, perhaps a reflection of maintenance behavior more than of differences in the probability of malfunction verification, is significant beyond the .001 level.††

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* In 1961, analysis of all of the ASB/4 data in connection with the contract for which it was collected, showed that the probability of verification decreased with (a) increased initial delay time (b) increased malfunction number within a work order and (c) increased numbers of unverified malfunctions within a work order. In Table 7 mention was made of the effect of symptom length upon verification. And in Section IV, paragraph 1.9 the discussion of the relationship between intermittancy and verification was begun.

** Significance levels using a binomial probability test.

† Significance levels using a chi square statistic.

†† Significance level using a binomial probability test.

2.4 Personnel Assignment

For these data, there are three methods of detecting personnel assignment biases. First, in the ASB/4 data manning profiles can be compared (numbers of men at various skill levels) for various units removed. This treats "unit removed" as a definition of the job. The relationship between manning profile and unit removed is significant ($p < .001$). This simply means that certain units are removed by certain numbers of men or certain skill-levels or both.

Second, one can separate ASB/4 symptoms themselves into job descriptions. Jobs are described as before (see Table 10). The relationships between numbers of men at various skill levels are significant for both preventive and corrective maintenance ($p < .01$ for 3 and 7 level technicians and $p < .05$ for 5 level). The differences between preventive and corrective maintenance are also significant ($p < .01$).

Third, for the Dover F-106 data it is possible to "correlate" (see Section 4.3) symptom to the identity of the maintenance man assigned. This yields a constraint of 26.6%.

3. INFORMALYTICS*

During the progress of this research, the investigators were requested to exercise a portion of their collective acumen on a potpourri of F-106 data which had been collected in a large study directed at defining system problems rather than at solving specific problems (ref. 7). It was reasoned that the information theory metric measures the amount of information communicated through a channel. An input device codes the information; a transmission line carries the information; an output device decodes the information. This is the general problem description. It is a GENERAL problem description and information theory MEASURES the amount of information transmitted. Any pair of cooccurring events can be cast in this problem description.

Informalytics is a quantification technique which can be applied to qualitative data.

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* Informalytics is a word coined here to refer to the use of information theory as an analytic tool to evaluate data. As such it includes the application of information and uncertainty measures as a technique for assessing correlation, dependence, and structure, and it also includes the statistics necessary to evaluate the likelihood implications of any particular observation, (cf Section 3.1).

As this concept matured, the work required for the two studies (the study reported here and the one on the F-106) merged. Each study profited from the activity of the other. The F-106 study exploited the computational philosophy developed for this study —— and funded the computerization of the second set of programs, the bivariate analyses. The present study obtained a good sample of shop maintenance data and achieved a much enlarged point of view.

The following paragraphs repeat the significant content of the F-106 study. This is appropriate because (a) the F-106 program was directed at an audience unrelated to this one (b) this portion of the F-106 work is corroborative to other portions of the present study (c) this work represents an extension of concepts first applied in the present study and as such (d) this work introduces a new tool to the technology of quantifying human performance. The arrangement of these paragraphs is similar to that employed in section IV, paragraph 2, one subsection for each maintenance or system criterion.

3.1 Malfunction Verification

The total uncertainty in reported verification is 1.08496 bits. Table 11 summarizes the results of several correlations of this event with other attributes of the maintenance environment. The first eight of these correlations are with potential predictor variables, the second four relate to events that occur after the verification event. These are included to gain a picture of how well verification, as a measure of maintenance efficiency, is related to other measures of maintenance efficiency.

Table 11, and the others like it in succeeding paragraphs of this section, presents the results of information theory analysis of the variables listed. The first column indicates how many variables were used in the correlation to the major variable; in this table the major variable is malfunction verification. The second column names the variables used. The third column indicates how much uncertainty is available in the predictor variable. (The amount of information gained concerning the predicted variable can not exceed the amount available in the predictor variable.)

The fourth column lists how much predicted uncertainty is reduced by knowledge of the predictor variable.

The amount of uncertainty predicted by the predictor variable, expressed as a precentage of the predictor variable, is a measure of the efficiency* of the prediction (column 5). If <u>all</u> the data

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* See Section III, paragraph 1.2.

TABLE 11

PREDICTION OF MALFUNCTION VERIFICATION
U = 1.08496; E = 10.0%

Number of Variable	Predictor Variable	Uncertainty	Predicted	Efficiency, %	Percent of Total Accounted For
1	Pilot	6.10230	.55439	9.1	51.1
1	Mission Success	1.66678	.39025	23.4	36.0
1	Symptom	5.29164	.32461	6.1	29.9
1	Aircraft Number	5.63709	.26491	4.7	24.4
1	Maintenance Man	2.25079	.14107	6.3	13.0
1	Maintenance Concept	1.33009	.13573	10.2	12.5
1	Base	.88014	.07846	8.9	7.2
1	Severity	1.35768	.04234	3.1	3.9
1	Action Taken	1.83494	.33660	18.3	31.0
1	Method of Troubleshooting	2.78509	.26264	9.4	24.2
1	Next-Flight Success	2.03774	.17996	8.8	16.6
1	Downtime	3.48140	.15175	4.4	14.0
2	Maintenance Concept & Method of Troubleshooting	3.56814	.29092	8.2	26.8
2	Symptom and Pilot	8.97451	.97705	10.9	90.1
1	Mission Success	1.66678	.39025	23.4	36.0
2	Mission Success and Pilot	7.26773	.74823	10.3	69.0
3	Mission Success Pilot & Symptom	9.15490	1.02601	11.2	94.6

Note: "U" is the uncertainty and "E" is the efficiency (if all data were used)

Instructions for reading the table follow; those for calculating its entries were provided in Section III, paragraph 1.1.2; those for assessing the statistical significance of those entries were provided in Section III, paragraph 2.

were used to predict verification, efficiency would be as low as 10.0%. An appropriate value of this sort is presented at the top of each table in order to assess the relative usefulness of any of the tabled predictions.

The predicted uncertainty reduction divided by the total uncertainty of the predicted variable is the percentage of the total uncertainty which can be obtained through knowledge of the predictor variable. This percentage can be used directly as a measure of correlation. Furthermore, it is mathematically permissible to estimate an analogous product moment correlation coefficient as a function of the square root of this percentage (as explained in Section III, paragraph 1.1.2 and ref. 5). Finally, in the lower portion of each table the terms of a multi-variable prediction scheme have been collected. This analysis is similar to multiple regression. Here, however, instead of predicting with a formula, one predicts with a table.

3.2 Next Flight Success

Next flight success is an evaluation of whether or not the symptoms on this flight were repeated on the next flight. As such it is a clear measure of maintenance efficiency, but its interpretation must be tempered because the symptom could have repeated spontaneously, that is, it could be another malfunction of the same subsystem.

If maintenance personnel were perfect, the probability of next flight success would be independent of:

(1) Symptom - because all malfunctions would be fixed.

(2) Verification - because all malfunctions would be fixed and all unverified malfunctions would be good systems.

(3) Maintenance Men - because all men would be equally perfect.

(4) Base - because both bases would be equally perfect.

Table 12 checks some of these predictions and several others. The table is to be interpreted as before.

3.3 Down Time

Down time is the most common measure of maintainability. Table 13 examines this measure as a function of six other variables. For the upper portion of the table down time was considered in hours only, disregarding tenths of an hour. In

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TABLE 12

PREDICTION OF NEXT-FLIGHT SUCCESS
U = 2.03774; E = 18.8%

Number of Variable	Predictor Variable	Uncertainty	Predicted	Effi-ciency, %	Percent of Total Accounted For
1	Pilot	6.10230	.55925	9.1	28.5
1	Aircraft Number	5.63709	.46848	8.3	23.0
1	Symptom	5.29164	.40293	7.6	19.8
1	Method of Trouble-shooting	2.78509	.27952	10.0	13.7
1	Downtime*	3.48140	.27801	8.0	13.6
1	Unit	4.86252	.23669	4.9	11.6
1	Maintenance Man**	2.25079	.21129	9.4	10.4
1	Verification	1.08496	.17996	16.6	8.8
1	Maintenance Con-cept	1.33009	.16624	12.5	8.2
1	How Mal	2.47726	.13694	5.5	6.7
2	Symptom and Unit	7.98804	.85442	10.7	41.9
2	Method of Trouble-shooting & Main-tenance Concept	3.56814	.37202	10.4	18.3
3	Action Taken Method of Trouble-shooting Maintenance Concept	4.70519	.50382	10.7	24.7
1	Pilot	6.10230	.55925	9.1	28.5
2	Pilot and Symptom	8.97189	1.64989	18.4	81.1
	Pilot and Symptom and Unit	10.40586	1.78934	17.2	88.0

*Hours only
**Both bases, thus data have one number for <u>all</u> Selfridge men and one for each Dover man.

Note: Instructions for reading the table follow; those for calculating its entries were provided in Section III, paragraph 1.1.2; those for assessing the statistical significance of those entries were provided in Section III, paragraph 2.

TABLE 13

PREDICTION OF DOWNTIME
$U = 5.49548*$; $E = 50.8\%$

Number of Variable	Predictor Variable	Uncertainty	Predicted	Efficiency, %	Percent of Total Accounted For
1	Pilot	6.09102	1.21223	19.9	35.1*
1	Symptom	5.29164	.97879	18.5	28.3*
1	Unit	4.84940	.62937	13.0	18.2*
1	Method of Trouble-shooting	2.74523	.54021	19.7	15.6*
1	Maintenance Concept	1.33009	.24159	18.2	7.0*
1	When Discovered	1.18339	.22320	18.9	6.5*
1	Symptom	5.29164	2.06049	38.9	37.5
2	Symptom and Unit	7.97015	3.24639	40.7	59.1
3	Symptom and Unit and Trouble-shooting Method	8.40605	3.65380	43.5	66.5
4	Symptom and Unit and Trouble-shooting Method and Maintenance Concept	8.54002	3.78066	44.3	68.8

*Considered as a three-digit code. Single variable comparisons used downtime as a two-digit code (hours), $U = 3.45271$

Note: Instructions for reading the table follow; those for calculating its entries were provided in Section III, paragraph 1.1.2; those for assessing the statistical significance of those entries were provided in Section III, paragraph 2.

view of the success of the single variable predictions, tenths
of an hour were included in the multivariable analysis.

3.4 Unit

It is a stretch of the imagination to suggest that the unit
pulled in a maintenance action is somehow a measure of the
efficiency of that action. The only aspects of this which directly
hint of efficiency are those associated with whether or not the
unit is really bad. These aspects will be discussed in the next
two sections. Here, concern is only with discovering those
aspects of the total maintenance situation which would help to
predict which units will be involved. (That, after all,is the
problem of information transmission to maintenance men.) The
progress of this search is documented in Table 14.

3.5 A Summary

The reader will notice that Informalytics is a dramatic
method for pinpointing problem areas and for assessing the
relative impact of selected variables upon system performance.
In the F-106 avionics systems it appears (based upon the sizes
of the correlations available in Tables 11, 12, 13, and 14) that
variability in system performance is 2:1 a personnel problem
rather than an equipment problem.

It was not possible to check this observation by comparing
it to analyses in the ASB/4 data, as those data did not include
personnel identity in a sufficient number of cases.

TABLE 14

PREDICTION OF UNIT
$U = 4.86252$; $E = 44.9\%$

Number of Variable	Predictor Variable	Uncertainty	Predicted	Efficiency, %	Percent of Total Accounted For
1	Symptom	5.29164	2.16612	40.9	44.5
1	Aircraft Number	5.63709	1.12130	19.9	23.1
1	Pilot	6.09102	.28295	4.6	5.8
1	When Discovered	1.18339	.25205	21.3	5.2
1	How Mal	2.47726	.94531	38.2	19.4
1	Downtime	3.45261	.62937	18.2	12.9
1	Next-Flight Success	2.03774	.23669	11.6	4.9
1	Symptom	5.29164	2.16612	40.9	44.5
2	Symptom and Pilot	8.94240	3.37343	37.7	69.4
3	Symptom and Pilot and Trouble-shooting Method	9.12336	3.48108	38.2	71.6

Note: Instructions for reading the table follow; those for calculating its entries were provided in Section III, paragraph 1.1.2; those for assessing the statistical significance of those entries were provided in Section III, paragraph 2.

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SECTION V

DISCUSSION AND CONCLUSIONS

Section IV provided a quick overview of the major analyses associated with this study, but did not suggest many interpretations of those analyses. Rather, in the interests of uncomplicated presentation, Section IV primarily presented the results; this section will consider some of the reasonable interpretations.

1. INFORMATION TRANSMISSION

The results of this study clearly demonstrate that symptoms carry information; it is the purpose of this section of the report to interpret where and how this information is conveyed.

1.1 Unit Designation

There can be no doubt that the reported symptom conveys information of assistance in trouble-shooting. In fact, it is clear (a) that there is more information available than maintenance men use (since they do not trouble-shoot optimally, see section IV paragraph 1.2) (b) that there is more information available to the operator than the symptom contains, (since the operator himself is a significant variable in the selection of the symptom) (see section III, paragraph 1.1.2 and paragraph 2.2 of this section) and (c) there is more information available to the maintenance man than is contained in the symptom (since he is more efficient at trouble-shooting than a computer could be using the same symptoms and an optimum search strategy but no additional information).

The subject of the reported symptom was again shown to contain most of the unit designation information. (It reduces total uncertainty as to which black box is the bad one by more than 60%.) The other characteristics of the malfunction report seem to constrain malfunction verification likelihood and malfunction verification time.

1.2 Malfunction Verification

The symptom conveys a considerable amount of information concerning the issue of malfunction verification, but most of it is about personnel behavior and not about the true verification of malfunctions.

Malfunction verification seems to be a paperwork problem. Personnel are motivated, for a variety of reasons, to claim that a malfunction has been verified. (If a maintenance man

fails to verify a malfunction and the symptom is reported again on the following flight, he suffers more than chagrin.) Accordingly, it is not surprising that the factors which produce high flight line verification rates also tend to produce high bench check OK rates.

An examination of the 407 F-106 shop symptoms (written by the maintenance man to the shop) showed that intermittent symptoms have a much higher "bench check OK" rate than stable symptoms. This information, and the fact that intermittent symptoms are much more likely to lead to a unit removal than stable symptoms (98% of the time vs. 62% of the time) lead to some interesting conclusions. It appears that the maintenance man has less faith in his failure to verify an intermittent symptom than he does in his failure to verify a stable symptom. This is very much like the partial reinforcement effect in psychology. The maintenance man may test the equipment and find nothing wrong, but since the symptom was intermittent anyway he may decide that it "just wasn't malfunctioning on this try" and go ahead and replace a suspected unit - often removing a good one. (This is not meant to imply that intermittent symptoms do not exist, but merely that they are harder to verify. -- note that verification time, indeed all categories of time are longer for intermittent symptoms).

In connection with intermittent symptoms it is interesting to note that in spite of a near 100% verification rate, they contain a disproportionate number of misleading reports. Fourteen symptoms were coded by the field engineers as "misleading" symptoms. Of these misleading symptoms, 55% contained the word "intermittent," whereas only 7% of all of the reported symptoms contained this word.

The presence of a modifier or qualifying phrase in F-106 shop symptoms is positively related to high "bench check OK" rates. This is probably true for much the same reason as it is for intermittent symptoms. A modifier often implies that a symptom occurs only at certain times (e.g. "in banks and turns" or "after 5 miles") and is therefore quite hard to verify on the flight line, where "banks and turns" are difficult (if not impossible) to simulate. For this reason, again, good units may be removed if they are suspected of causing the difficulty.

On the other hand, for flight line symptoms, the presence of a modifier corresponds to an increased likelihood of verification. It is not certain whether this is due to an increased likelihood that the malfunction really occurred, or due to the effect increased verbage has on the credibility of the report.

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1.3 Maintenance Time

The symptom is the first element of the maintenance event and may be legitimately assumed to be a significant determiner of subsequent action. After all, there would be no justification for reporting a symptom, nor for listening to it, if one didn't believe that it reduced his uncertainty about what went wrong. Knowing what is wrong should be tantamount to knowing how long it will take to fix it. The data here suggest that maintenance time could be predicted from symptoms.

When jobs are carefully defined in terms of the reported symptoms, every category of maintenance time seems to be a function of the job — even administrative delay time! This result is intuitively reasonable and an "interpretation" is obvious as stated.

Preparation time and fault location time are significantly affected by the mood of the symptom. The trends here are for increasing objectivity of mood to correspond with decreasing time requirements for trouble shooting. This is consistent with an interpretation which suggests that as operators become less "emotionally involved" in reporting the malfunctions, they become more efficient in really communicating the difficulty. Notice that the differences in information transmission were also consistent with this view. (Increased "emotionality" could correspond to an increased likelihood of an invented symptom, but then the trend in probability of verification would be exactly opposite to that observed). It might be appropriate to reflect on the problem of mood and consider training and evaluation and morale procedures which, at little expense, could move operator involvement to a more efficient point on the motivation-performance curve (shades of the Yerkes-Dodson law).

Malfunction verification time is significantly related to the description in the symptom. This is probably because the description describes what the system is or is not doing and it is therefore related to the verification criteria.

Finally, every category of maintenance time increases for intermittent symptoms — probably because they are more difficult. (This interpretation is also supported by the higher incidence of high level technicians on "intermittent" jobs.)

2.   THE MAINTENANCE SYSTEM

In section IV, paragraph 3, informalytics (information theory used as an analytic tool) indicated a number of useful relationships between various characteristics of the maintenance

environment and certain measures of system performance. These relationships are collected and interpreted in the following paragraphs.

2.1 Organizational Structure

The two F-106 bases studied are differentially effective at maintenance. One has a probability of next flight success of .70 while the other has a probability of next flight success of .49. These values are statistically different, but that is not as important as the fact that they are functionally different. The first gets more planes flying successfully. There are a lot of differences between the two bases in terms of flight line procedures. Maintenance concepts (item 21 Appendix II) are differentially applied to differentially likely symptoms. For example, at the first base, MA-1 personnel are more frequently used by themselves than they are at the second base. However, the most important organizational factor seems to be the assignment of men and aircraft to squadrons. At the first base there is both "pride of ownership" and a "feeling of responsibility" for the aircraft. At the second base, the complexion of the maintenance job is different. Here a technician is really confronted with an assignment to dispose of a maintenance action on a relatively anonymous airframe, while at the first base he must fix one of his aircraft. It appears from the data that such a difference in attitude might have a demonstrable effect on maintenance performance.

2.2 Pilot

To begin with, very late in the F-106 analysis it was learned that pilot number is not unique; halfway through the data collection period many pilots exchanged code numbers. This change means that pilot number XX now refers to a particular pair of pilots rather than to a specific pilot individually.*

Using the information theory approach (see section III, paragraph 1.1.2), pilot is correlated to symptom; about 36% of the uncertainty in symptom can be obtained from the pilot's code number. Since aircraft number is also related to symptom, it is possible that the pilot-symptom correlation is spurious and really due to a pilot-aircraft-symptom correlation. The correlation between pilot and aircraft within a given squadron for one whole year was checked -- the effect is small (overlap of only 11%). Apparently, pilot is related to symptom. It is not possible, in this sample size, to determine if this

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*This confounding means that the calculated "correlations" with pilot are probably lower than they should be. The time required to redo the analysis exceeded the time left for completing the study.

relationship exists because some pilots report only certain
symptoms, or because some pilots report at random, or both.
(Further study would be required to answer this question.)

Pilot number is significantly related to down time (35%).
This is probably a reflection of the effect noted above. A
pilot reports a symptom which does not contain a lot of infor-
mation (e.g. he makes an error in reporting because he is
inexperienced, or he reports a bogus symptom in order to cover
a mistake he made) and maintenance time increases. Another
pilot gets right to the point with his symptom and maintenance
time decreases.

Pilot number is correlated to next flight success, but
the reasons for this are not apparent. Do some pilots fail to
report malfunctions? Do some pilots give their symptoms so
loosely that maintenance personnel can't find the problem?
Do some pilots report their systems so concisely that maintenance
personnel can easily peak the equipment up?

Finally, pilot number is significantly correlated to
malfunction verification (51%). A full one-half of the uncer-
tainty concerning whether or not a given malfunction will be
verified can be obtained if one knows who made the complaint,
i.e. even if you ignore what the complaint was.

2.3 The Maintenance Man

For the ASB/4 data, the only indications of personnel
assignment bias possible were dependences of skill level and
numbers of personnel upon symptom and unit action. Chi
square tests justified the claim that such a dependence existed,
but it could have been as a result of the job, that is, it
could have occurred after work started and not necessarily be
an assignment bias. (For either condition the relationship
proves that symptom per se is a commentary on job complexity.)

For the F-106 data at Dover, flight line personnel codes
were available for the personnel assigned to the maintenance
action. There is an assignment bias; symptom and man correlate
(26.6%). At least a portion of this is to be expected because
some of the men belong to the Flight Control Shop and some
belong to the Radar Shop. The overlap between man 1 and man 2
is 33.2% which means that a very strong assignment bias is
operating within shops.

Maintenance man code number overlaps with system down time
29.7%. A portion of this could be due to a man-symptom-down
time chain of relationship. It is probably not all due to that
effect, but it cannot be checked; the present sample size is
too small.

Maintenance man is also related to trouble-shooting method
(25.7%). To the extent that trouble-shooting method is impor-
tant, and to the extent that this relationship is independent
of symptom, this could be an important observation. Important
choices certainly should not be made on the basis of individual
whim. As it happens however, trouble shooting method doesn't
seem to be particularly important (see below), and both it
and man depend, at least a little, upon the symptoms.

The story with maintenance concepts is different, but the
result is roughly the same. The overlap is large (21.6%)
and perhaps spurious. Certain men who can work concept 2
(FC & M personnel only) cannot work concept 3 (MA-1 personnel
only). This structure could be enough to generate the observed
bias.

2.4   Trouble Shooting Strategy

The F-106 data contained a coded description of the
trouble-shooting method employed. A correlation of this
variable produced some surprising results. To be sure, symptom,
the maintenance concept, and maintenance man are each importantly
related to the choice of a trouble-shooting method. On the
other hand, choice of trouble shooting method does not appear
to be very importantly related to the various measures of main-
tenance efficiency. In particular it is insignificantly related
to the probability of next flight success and unimpressively
correlated to shop action taken.

The inability to detect significant relationships does
not mean that the choice of a trouble-shooting method is
unimportant. As was noted earlier, the problem may be one of
applying the strategy rather than of choosing it. The repaired
vs. bench check-OK record for all units involved in six symptoms
(RHH, RH, FN, FT, FA, FD) was examined. In every case the
total number of bench check-OK units was less than the minimum
predicted by any optimizing strategy. Clearly, the maintenance
man must have had some additional information (cf section V,
paragraph 1.1). On the assumption that the proportion of
bench check-OK units would be a function of strategy, Wilcoxon
and Chi square test were used to compare the observed relative
proportions of bench check-OK's to the various predicted pro-
portions. All of the optimum strategies were easily rejected.

On the basis of this analysis it appears that the maintenance
personnel select a trouble-shooting strategy on the basis of
what they think will work in that context. This selection of a
method may be random and unimportant, or it may be totally
biased but assigned on a very sound basis. At any rate, the
man very soon gathers a significant amount of new information
concerning the symptom, and this change in the maintenance

event now affects his subsequent behavior in nonoptimum, but presently undescribable, ways. Thus one can now predict how the maintenance man will start trouble-shooting, and one can be sure that the maintenance man is not following an optimum path, but one cannot predict what happens during trouble-shooting, or what the maintenance man will end up doing. One can predict the unit to be removed as a function of the symptom, but one really can't predict unit very much as a consequence of trouble-shooting procedure. Based on trouble-shooting strategy one can presently predict a trivial amount of down time, and this only because of inefficiencies in trouble-shooting paths. On the other hand one cannot predict next flight success at all, because all the trouble-shooting procedures which were observed were equally effective (or equally ineffective as the case may be) at discovering the offending unit.

In general, one can conclude: (1) the maintenance man is operating on more information than that contained in the pilot's symptom. (2) the maintenance man is not using any optimum strategy. (A decision should be made concerning the relative "costs" of removals and tests and a prescribed trouble-shooting procedure should be required.) (3) the average F-106 total down time could be reduced (perhaps as much as 35 minutes out of -- minutes currently used) if maintenance men were encouraged to use mock up checks in lieu of special test equipment, local test equipment or multimeter testing. Furthermore, single unit substitution is a relatively time consuming operation but whole-sale unit swapping, while reducing total down time an average of 1.65 hours, encourages high bench check-OK rates. This simply underscores the fact that there is a trade-off here between shop and flight line manhour expenditures.

2.5 Paper Work

In the data analyzed here there was no direct way in which to evaluate the impact of paper work upon measures of performance. The absence of direct paths not withstanding, there is an interesting implication available.

It appears as though it is possible to have the paperwork actually degrade system performance while it records system performance as improved. Consider an operator who commits an error of judgement on one of his attempted missions. He is evaluated (paperwork) on his performance, so he blames the equipment in order to get "out from under" the error. A maintenance man is sent out to the airplane, and he gets evaluated in terms of how many malfunctions he says he fixes. So he "verifies" the complaint and pulls a box in order to up his "batting average." Meanwhile the aircraft is out of service. Finally the system is placed on up status following unnecessary repair. It now has a higher probability of failing on the

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next flight than had it not been "repaired" for the man has disturbed the balance of the system. All the paperwork says that everybody was efficient, but the system as a whole is actually worse off.

3. RECOMMENDATIONS

This study had five purposes or goals (cf Section I, paragraph 2). The first and fourth were concerned with trying to use information theory on maintenance data, and the existence of Sections IV, paragraphs 1 and 3 demonstrates the completion of those tasks. The second goal was concerned with assessing the location of information in malfunction reports, and that was disposed of in Section IV, paragraph section V, 2 and 1. The remaining two goals required the development of recommendations for improving maintenance efficiency and for improving system efficiency. These tasks are dealt with in the following paragraphs.

3.1 Training Operators in Failure Reporting

It is clear that some of the significant characteristics of a symptom cannot be directly converted into neat little recipes for operator training. Training an operator to always say "change dessicators" no matter what is wrong certainly will not minimize maintenance time, even though this symptom is a very easily diagnosed symptom and the job referred to is a very easy job. The problem is to improve the transmission of information already available, not to try to create information to be reported. (That problem will be attended to later.)

It is recommended that an on-site training program be instituted for system operators. Such program should run for approximately 3 hours and should cover:

     (a)   Maintenance men are also being given some refresher training.

     (b)   Maintenance cannot be effective if equipment is not referred for maintenance.

     (c)   Maintenance cannot be effective if equipment malfunctions are not properly described.

     (d)   Some of the characteristics of the data of this study.

The reasons for this recommendation are several, but major support can be found in these three:

1. Some pilots appear presently to be withholding malfunction information because "What the hell, they can't fix it anyway."

2. Some pilots appear to be writing up equipment malfunctions too glibly and not giving the proper details.

3. Some pilots appear to be writing up equipment malfunction reports for their own errors.

There are certain things which can be done outside of the area of training operators which probably would have broader and more important benefits.

1. Modify the debriefing process, based upon an analysis of the equipment, to include prescribed questions concerning the conditions surrounding the malfunction. These questions would be used to separate one symptom from another, and to indicate whether or not a malfunction has really occurred. (One could even provide the operator with an in-flight self-debriefing form).

2. Modify the operator evaluation system so that he is evaluated on how well he and the equipment perform. This will remove the temptation to "blame" the equipment for marginal system performance which is due to the operator, or to both the operator and the equipment.

3. Modify the maintenance evaluation system so that the maintenance man is also evaluated on system performance. If this is accomplished successfully, say by using conditional probability rules and by evaluating teams of men and equipment, then personnel will be motivated to fix equipment rather than to "fix" paperwork. The difference should be important.

4. Train maintenance men to understand the transmission of information and how it implies certain rigid trouble-shooting sequences. This should improve their efficiency and make the case for training operators, above, more convincing to the operators.

3.2 Trouble-Shooting

The data here are entirely consistent with the theory and predictions of the Symptom Matrix* (ref. 1). Clearly, the symptom does carry information; equally clearly, the maintenance man does not use the information optimally. This lack of optimality may be because (a) he doesn't know what to do with the information he receives, (b) he is not able to "perceive" the information, (c) he does not accept this definition of optimum, (d) he does not choose to do his best, or of course, (e) some combination of these effects.

It would be interesting to learn which of these situations prevails, and experiments with experienced maintenance men could determine that:

1. Prepare a paper and pencil test, multiple choice, asking the maintenance personnel which of "these" black boxes he should check first when given "this" symptom.

2. Construct an illuminated block diagram (like a training aid) and ask the maintenance man to predict which black box will be bad given "this" symptom. Monitored over a period of time, this probability choice experiment would ascertain (a) the course of development of perception of a complex probability structure and (b) the utility structure of the maintenance man's trouble-shooting philosophy.

3. Collect detailed data concerning the sequential tests employed in the field maintenance of a specific symptom. This will provide a sample of actual trouble-shooting sequences which could be compared to various projected strategies. In this manner, one would be able to test the validity of several predicted approaches. What does the maintenance man try to make optimum: down time, number of tests, part procurement trips, his evaluation record?

On the other hand, one does not have to know why things are not optimum in order to improve the situation. Of course the improvement could be based on a sounder rationale if the specific areas of suboptimization were known, but a general sweeping program could be of benefit anyway. The Symptom Matrix provides a set of implementation potentials which could be constructed for some small piece of equipment, about the

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*This document described a technique for predicting symptom and discussed the utilization of such predictions. All the predictions of this report which could have been tested by the present study were confirmed by the present study.

complexity of a color TV set. From this matrix, design
recommendations for packaging and monitoring, training aids
and trouble-shooting aids should be developed and compared to
current practice. This direct approach to the problem of
maintenance efficiency is warranted in light of (a) the need
for improved maintenance and (b) the body of evidence supporting
a Symptom Matrix approach.

APPENDIX I

B-52 DATA: WALKER AFB

Variable	Variable Explanation
1. A/C Identification	Base originated code number
2. Flight Number	Consecutive within each A/C
3. Date of Event	Day, Month, Year
4. Type of Event	Assigned Code:

      1. Flight and subsequent associated maintenance

      2. Maintenance to correct additional malfunction(s) detected during post-flight maintenance

      3. Maintenance following operator pre-flight complaint

      4. Maintenance to correct mainte-nance observed malfunctions other than those covered by code 2

      5. Test Control Report

    *8. Supplementary Report

      9. Other

5. Type of Mission   Assigned Code:

      1. RBS, Radar
      2. Camera, Attack
      3. Navigation Only
      4. RBS, Radar and Camera
      5. RBS, Radar and Other
      6. Camera Attack and Other
  **9. Other

---

 * Numbers (6) and (7) not used as codes here.
** Numbers (7) and (8) not used as codes here.

6. Length of Mission   To nearest 1/10 hour

7. System Type   Assigned Code:

                              A ARC-65
                              B ARC-34
                              C AIC-10
                              D ARA-25
                              E APX-25
                              F ARN-21
                              G APN-21
                              H MD-1
                              J ASB-4
                              K ASB-4A
                              L ASB-9
                              Z System not under surveillance

8. System Number   For systems used in multiples on
                             the A/C

9. System Rating   Flight crew rating, assigned code:

                             0. Not used
                             1. No maintenance required
                             2. Maintenance required
                             3. Training lost due to this system
                             4. Flight cancelled due to this
                                system
                             5. Flight cancelled due to another
                                system under surveillance
                             6. Flight cancelled due to system(s)
                                not under surveillance
                            *9. Other

10. Symptom   4-digit code (See Appendix C)

11. Maintenance   Action taken, assigned code:

                             1. Checked; not trouble found
                             2. Repaired by unit replacement
                             3. Repaired by Sub-unit replacement
                             4. Repaired by Part replacement
                             5. Repaired by part adjustment
                             6. Repaired by part repair
                             7. Modified, cannibalized, switched,
                                 etc.
                             8. Repair action performed outside
                                 system
                             9. Other

_____

*Numbers (7) and (8) not used as codes here.

A. 2-3 (ie., both -- as given above)
B. 2-4
C. 2-5
D. 2-6
E. 3-4
F. 3-5
G. 3-6
H. 4-5
J. 4-6
K. 5-6
L. 3 or more code numbers
N. 2-8
P. 3-8
R. 4-8
S. 5-8
T. 6-8

12. Unit   4-digit code (last digits of manu-
                            facture designation).

13. Unit Maintenance   Action taken, assigned code:

                            1. Checked; no trouble found
                            3. Repaired by subunit replacement
                            4. Repaired by part replacement
                            5. Repaired by part adjustment
                            6. Repaired by part repair
                            7. Switched, modified, cannibalized,
                               etc.
                           *9. Other
                            E. 3-4
                            F. 3-5
                            G. 3-6
                            H. 4-5
                            J. 4-6
                            K. 5-6
                            L. 3 or more code numbers

14. Serial Out   Last four digits of removed unit
                            serial number

15. Serial In   Last four digits of new unit serial
                            number

16. Sub-Unit   4-digit code

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*Number (8) not used as a code here.

17. Sub-Unit Maintenance   Action taken, assigned code:

        1. Checked; no trouble found
        4. Repaired by part replacement
        5. Repaired by part adjustment
        6. Repaired by part repair
        7. Switch, modified, cannibalized, etc.
        H. 4-5
        J. 4-6
        K. 5-6
        L. 4-5-6

18. Serial Out   Last 4 digits of removed sub-unit serial number

19. Serial In   Last 4 digits of new subunit serial number

20. Part Circuity Symbol   7-digit circuit symbol

21. Part Name   6-digit code

22. Part Defect   3-digit code

23. Part Maintenance   Action taken, assigned code:

    *4. Replaced
     5. Adjusted
     6. Repaired
     7. Modified, cannibalized, etc.
     9. Other
     K. 5-6
     M. Complete standard alignment

24. Shop/Depot Date   Day, Month, Year of completion at this level

25. NRTS (Not Repairable This Station)   Reason, assigned code:

     1. Unit sent to depot for repair
     2. Subunit sent to depot for repair
     3. Unit repair attempted; unsuccesful; sent to depot for repair
     4. Subunit repair attempted; unsuccessful; sent to depot for repair

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* Numbers (1) through (3) and number (8) not used as codes here.

<div style="margin-left: auto; width: 60%">

5. Unit scrapped
6. Subunit scrapped
7. Same as 2, use if not first subunit reported
8. Same as 4, use if not first subunit reported

</div>

26.	Report Number	Consecutive for each A/C
27.	Malfunction Number	Consecutive within a report
28.	Reason for Maintenance	Numbers for flight line; letters for shop, assigned code

<div style="margin-left: auto; width: 60%">

1 (or A) To correct operator complaint
2 (or B) To correct maintenance complaint
3 (or C) Periodic check
4 (or D) Modification, recycle
5 (or E) Activity following operator in-flight maintenance
6 (or F) To correct preflight complaint
7 (or G) To verify complaints only
8 (or H) Cannibalization only
9 (or J) Unknown

</div>

29.	Malfunction Verified?	Yes, No, N/A
30.	Number of Men	Number of 3,5,7 level technicians
31.	Preparation	Activity code; time in hours and 1/100ths
32.	Malfunction Verification	Activity code; time in hours and 1/100ths
33.	Fault Localization	Activity code; time in hours and 1/100ths
34.	Part Procurement	Activity code; time in hours and 1/100ths
35.	Repair	Activity code; time in hours and 1/100ths
36.	Final Malfunction Test Time	For each malfunction, clock time
37.	Final System Test Time	For each system, clock time

38. Time System Available   Clock time to nearest hour that flight ended

39. "On time"   Filament or standby time accumulated during maintenance

40. Administrative Time   Kind (coded as given below), time in hours

     1. System Administrative time
     2. Malfunction administrative time
     3. System and malfunction logistic time
     4. Unknown

41. Logistic Time   Code for kind of time, and time in hours and 1/100ths of hours

     1. System logistic time
     2. Malfunction logistic time
     3. System and malfunction logistic time
     4. Unknown

42. Initial Delay Time   Hours between time system became available and time active repair started

In addition, verbatim symptoms were elaborately (linguistically) coded - see Appendix D

APPENDIX II

F-106 DATA: DOVER AND SELFRIDGE AIR FORCE BASES

Variable	Variable Explanation

1. Base   Dover vs. Selfridge

2. Squadron   95th Fighter-Interceptor Squadron (FIS) - Dover; 94th and 71st (FIS) - Selfridge

3. Pilot Number   Locally assigned; not necessarily unique

4. Aircraft Number   Last 3 digits of serial number

5. Aircraft Report Number   Sequentially assigned by event within A/C number

6. Date   Day, Month, Year

7. Cumulative Flight Hours   On this A/C

8. Mission Type   Assigned code:

1. Active ADC missions
2. Intercept sorties during tactical evaluations and Operational Readiness Inspections (ORI's).
3. Intercept sorties during other exercises
4. Intercept sorties during normal training
5. Functional check flights
6. All other missions

9. Mission Success   Pilot's Rating of System Readiness - 1, 2, or 3

10. Mission Evaluation   Aborted (where) or other

11. Passes Attempted   Number of intercepts attempted during mission

12. Passes Completed   Attempted minus number of symptoms reported

13. Report Type   Symptoms classified into 7 general areas

14. Reason for Report   Assigned code:

                                          1. Flight
                                          2. Air Abort - flight control system
                                          3. Air Abort - MA-1 system
                                          4. Air Abort - Not FSC or MA-1
                                          5. Ground Abort - FCS
                                          6. Ground Abort - MA-1
                                          7. Ground Abort - Not FSC or MA-1
                                          8 Maintenance Originated Complaint, Unscheduled
                                          9 Maintenance Originated Complaint during Scheduled Maintenance

15. Malfunction Number   Consecutively within A/C Report Number

16. Symptom Code   From 76-3 Form as reported by ADCR-

17. When Discovered   Taken from AFM 66-1 codes

18. Severity of Complaint   ARINC Research Field Engineer's rating - 1, 2, 3 or 4

19. Verification of   Assigned codes:
     Complaint

                                            1. Specific Operator Complaint Verified
                                            2. Not Verified, other trouble found in some subsystem
                                            3. Not Verified, other trouble in other subsystem
                                            4. Maintenance Originated Complaint
                                            5. Not checked
                                            6. No data available
                                        *9 No trouble found

20. Action Taken   From T.O. 1F-106-06 code

21. Maintenance Concept   Assigned code:

                                            1. Team Concept Used
                                            2. FC&M Personnel only
                                            3. MA-1 Personnel only
                                            4. Mechanical Personnel only
                                            5. Any of the above plus Technical Rep. Assistance

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* Numbers (7) and (8) not used as codes here.

22. Method of Trouble   Assigned code:
    Shooting

                               1. Self test features
                               2. Unit substitution
                               3. Wholesale unit substitution
                               4. Special test equipment
                               5. Short system ground check
                               6. Multimeter testing
                               7. Locally built test devices
                               8. Visual inspection
                               9. Other
                               A Steering loop alignment
                               B Mark-up check

23. Next Flight Success   Assigned code:

                               0. Unknown or indeterminate
                               1. Successful
                               2. Not successful - similar symptom
                               3. Not successful - new symptom
                               4. Failed prior to next flight
                               5. Not applicable

24. AFCS Subsystem Downtime   Total maintenance delay time in
                               tenths of an hour

25. Work Unit Code   From T.O. 1F-106-06 code for each
                               unit involved

26. Flight Line Action for   Assigned code:
    Unit

                               0. TCTO or special test requirement
                               1. Adjust unit in place
                               2. Remove - replace, no adjustment
                                  required
                               3. Remove - replace, adjustment
                                  required
                               4. Remove - reinstall, no trouble
                                  found in shop check
                               5. Remove - reinstall, repaired in
                                  shop
                               6. 4 plus additional adjustment in
                                  A/C
                               7. 5 plus additional adjustment in
                                  A/C
                               8. Replace parts or assemblies in
                                  place
                               9. Make other repairs in A/C

27. Unit Serial Number   Last 4 digits of serial number

28. Unit Report Number   Consecutively within serial number within W.O.C.

29. Unit Cumulative Hours   Estimated total operating hours

30. How Malfunction (Unit)   Symptom to shop from AFTO 210/211 form

31. Reason for Action (Unit)   Assigned code:
    0. Termination
    1. Suspected unit malfunction
    2. Removed for bench check
    3. Removed as one unit of a group swap action
    4. Removed during scheduled maintenance
    5. Removed for special inspection or TCTO
    6. Installed, OK
    7. Installed, Not OK

32. When Discovered (Unit)   From T.O. 1F-106-06 code list

33. Action Taken/Disposition (Unit)   Assigned code:
    0. Reseated sub-unit
    1. Adjust only
    2. Replace subunits
    3. Replace parts (electrical)
    4. Replace parts (hardware)
    5. Combinations of 2, 3, and 4
    6. Repair wiring, connectors, or solder joints
    7. Clean and/or lubricate
    8.
    9. No trouble found
    A. NRTS, lack of parts
    B. NRTS, lack of technical skill
    C. NRTS, lack of test equipment
    D. NRTS, sealed unit
    E. NRTS, beyond local repair

34. Method of Fault Isolation (Unit)   Assigned code:

    0. MAAMA testers
    1. Test stand procedures
    2. Special test equipment
    3. Locally built test devices
    4. Ohmmeter, resistance testing
    5. Visual inspection
    6. Other
    7. TRT Tester
    8. Previous experience
    9. 96089-801 tester

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35. Unit Active Repair Time   Manhours, for shop, in tenths of
                               an hour

36. Flight Line Personnel 1   Name code (Dover only) of mainte-
                               nance supervisor for this action

37. Flight Line Personnel 2   Name code (Dover only) of mainte-
                               nance man #2 on this action

38. Squadron - Flight   A, B, or C according to work shift

APPENDIX III

SYMPTOM REPORTING

1. INTRODUCTION

This appendix describes how symptoms are currently being reported in the Air Force maintenance system and also how they were being reported during the data collection periods for the data studied here. In order to do this, the appendix is divided into four parts. The first part deals with current Air Force regulations concerning symptom reporting as contained in AFM 66-1. The second part covers symptom reporting procedures at Walker AFB (SAC) from March 22, 1960 until April 6, 1961 -- the period during which the primary ASB-4 data considered in this study was collected. The third part examines symptom reporting procedures at Dover AFB (ADC) from November 1965 to February 1966 -- the period during which data concerning F-106 electronic subsystems, also included in the study, was collected. The fourth part contains brief description of current reporting procedures at certain other Air Force Bases from which first hand experience and information are available.

2. MAINTENANCE PROCEDURES RELEVANT TO SYMPTOM REPORTING SPECIFIED IN AFM 66-1 (1965)[1]

Aside from prescribing a very general organizational structure within which symptoms are reported, AFM 66-1 does not specify the specific communication nets to be employed by individual bases. The one procedure relevant to symptom reporting which AFM 66-1 does specify is the use of post flight debriefing. The regulation specified that:

> "For those major commands operating complex
> weapons systems, an operator-maintenance
> debriefing procedure will be utilized.
> Through detailed debriefings of operating
> crews experience and complete analysis of
> reported discrepancies, many maintenance
> manhours may be saved by knowing what the
> trouble is and what is required to correct
> it prior to scheduling maintenance action."
> (Section 2 paragraph 23)

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[1] AFM 66-1 was revised 15 July 1966, after this study was underway; reference is being made here to the preceding edition. The procedures have not been materially changed in the newer edition. Distribution copies were not available when this draft was prepared.

This clearly places the operator-maintenance debriefing in the
central position as far as routine symptom reporting is concerned.
(It is also obvious from the above paragraph that symptoms are
considered an important factor in maintenance efficiency.)
AFM 66-1 does indicate that the reported symptoms (from the
debriefing session) should go directly to maintenance control,
and from there to the flight line maintenance personnel (via the
maintenance supervisor).

In general then, the prescribed chain of symptom information
is: operator-maintenance debriefer - maintenance control -
maintenance supervisor - flight line maintenance personnel. Other
information channels are not precluded, but they are left up to
the discretion of individual commands and/or bases. There is a
certain amount of leeway in the details of the symptom reporting
situation.

ADC Sup. 1 to AFM 66-1 provides more detailed recommendations
concerning the specific ways in which AFM 66-1 regulations are
to be implemented for ADC commands:

> "The form specifies that a complete debriefing
> team must be available for all missions, and
> that a complete debriefing team consists of at
> least the following personnel:

> (1) An aircrew member highly skilled and
>   experienced in the aircraft and qualified
>   to interpret malfunctions in the weapons
>   systems.

> (2) An APG technician

> (3) An A & E (Armament and Electronics)
>   technician

When applicable or required, a radar intercept officer and
an engine technician are added to the debriefing team. ADC Sup. 1
makes special note that minimum requirements for F-106 units
"will include weapons control and integrated system technicians."
In addition to the above, crew chiefs are encouraged to participate
in the debriefing. The senior maintenance man on the team is the
debriefing team supervisor, and it is his responsibility to see
that the debriefing is properly conducted. The members of the
debriefing team usually return to their normal maintenance duties
when they are not required for debriefing duties. ADC Sup. 1
specifically states that "all members of the debriefing team will
be fully qualified in their specialties".

A cursory debriefing is to be conducted during approach,
landing, or shortly after landing by UHF radio or flight line
intercom. The minimum information to be conveyed at this time

must include relaying the status code[1] of any malfunctioning system to workload control. Immediately following the termination of any flight (or attempt) pilots and crew go directly to the debriefing area, taking aircraft forms with them. During directed exercises a modification of routine debriefing procedure is sometimes instituted. After a step-by-step debriefing, the debriefing documents are sent to workload control as soon as possible.

The regulations specify that "The procedures used in debriefing must be continuously reviewed to insure that aircraft are turned around with minimum delay", and that all documents reflecting system verification status be "reviewed and reconciled" monthly.

Even detailed supplements to AFM 66-1, such as the above, do not have provisions for non-routine methods of symptom reporting. The basic information channel is still operator - debriefer - maintenance control - maintenance supervisor - flight line maintenance personnel.

3.   SYMPTOM REPORTING AT WALKER AFB (SAC)-ASB-4 SYSTEM

The bombing navigator records in his flight log (Form #781) whether the system operated satisfactorily or malfunctioned during the mission. If he reports that the system did not operate satisfactorily, he also records the symptom(s) of the malfunction and whether or not in flight maintenance was attempted and successful.

After landing the crew is debriefed immediately by skilled representatives of the various maintenance shops. The A & E debriefer reviews the written flight log and also questions the bombing navigator in an effort to get precise information concerning any malfunctions which occurred. The debriefer then combines the data recorded in the flight log with the additional verbal information obtained during this interogation of the navigator. This combined description of malfunction symptoms is recorded on the job order form 992 which is sent to work load scheduling and the maintenance analyst.

Work load scheduling uses the information on the job order form to schedule work time so that congestion is avoided, and sufficient electric and hydraulic power is available for all maintenance actions. After the schedule for the maintenance

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[1]There are three codes: 1.) aircraft ready for next mission with servicing, 2.) aircraft capable of flying a mission, but some equipment modes are non-operable, and 3.) aircraft cannot fly another mission until maintenance is performed.

action is determined, this information (the schedule for the maintenance action) - and a copy of the job order form - are sent directly to the maintenance personnel who will ultimately troubleshoot the symptom(s). The maintenance personnel accomplish the work necessary to correct the symptoms associated with the malfunctions listed on the job order form, and they are responsible for rechecking any in-flight maintenance which may have been attempted. The verification status of symptoms, and information about what maintenance actions were taken, are sent to the maintenance analyst.

The maintenance analyst keeps records of all symptoms reported and all work done, and he keeps a performance history of each A/C. The maintenance analyst reports general maintenance trends and problems to the maintenance supervisor and to the work load scheduling. The maintenance supervisor, in turn, conducts daily "stand up" meetings with the maintenance personnel to review current maintenance problems and to assess the degree of maintenance effectiveness.

There are times when the above "routine" channels of information are not sufficient for effective maintenance. This is especially true when unusual maintenance problems occur, such as: repeat non-verified complaints, no trouble found, intermittent and self-corrected malfunctions, etc. When this happens, the maintenance personnel, maintenance supervisor and/or maintenance analyst may communicate directly with the system user (Bombing navigator) or debriefer. It should be noted that such direct communications are not routine and, therefore, are not recorded in the data used in this study.

In summary, symptom information comes to the flight line maintenance technician from some or all of the following sources:

(1)   Information recorded during debriefing on job order form.

(2)   Meetings with maintenance supervisor, which may use

    (a) Information from workload control

    (b) Information from maintenance analyst

    (c) Supervisor experience

(3)   Direct communication with system user or debriefer.

(4)   Symptoms observed during troubleshooting or malfunction verification.

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4. SYMPTOM REPORTING AT DOVER AIR FORCE BASE (ADC):
    ELECTRONICS SUBSYSTEMS

As the aircraft is preparing to land, or shortly after
landing and during taxi, the pilot is in radio contact with
Maintenance Control.

The pilot gives a verbal description of all symptoms to the
chief of Maintenance Control. The chief, who is assisted by a
number of additional personnel, is usually a highly skilled
ex-mechanical technician. Maintenance Control decides, tentatively,
if quick turn around of the aircraft is possible, if cursory
inspection might be fruitful (usually a matter of course), and
what general work facilities will be required. These decisions
are based on experience, as there are no fixed routines for each
set of possible symptoms.

Under most conditions the aircraft taxis to the cursory
inspection area, where flight line technicians have been waiting
and where they can talk to the pilot via intercom. (Prior to
hooking up the intercom, the flight line technician had been in
indirect contact with the pilot via relayed messages from Mainte-
nance Control.) Flight line personnel remove the Radar film
pack and send it back to the photo shop for immediate processing.
The flight line electronics technician, usually a senior skilled
technician, may then examine the aircraft's electronic subsystems
while they are still being supplied with aircraft-generated
power. He has 15 minutes to diagnose and fix the malfunction if
he can. If he can not fix it, or if he can't diagnose it, or if
he can not even verify the existence of the malfunction, then he
decides what facilities are required and assists Maintenance
Control in selecting a location for parking the aircraft. If
the malfunction was repaired in cursory, the aircraft can be
turned around quickly, and what follows in time is merely paper
work. If the aircraft was not repaired in cursory, then there
is always further work. (The technician is not allowed to "write-
off" the malfunction without action.)

After cursory, the aircraft is parked. Maintenance may
begin without paperwork if the maintenance supervisor for that
flight thinks it is desirable to start. Sometimes he was the
flight line technician at cursory and may feel that he has
special knowledge.

When the aircraft has been parked, the pilot goes immediately
to the debriefing area where he and other pilots from that flight
are met by operations and maintenance personnel and perhaps by a
Hughes technical representative. During debriefing, the film
record of the radar scope action is run, and an MA-1 (fire control
system) flight line maintenance officer (skill level E7 or above)
questions the pilot about his electronics subsystems complaints.

A 76-3 debriefing form and the 781 aircraft record are filled out at this time. An effort is made to define the pilot's complaint in terms of a 3-letter symptom code from the ADCR 66-28 code book. The maintenance officer and the pilot try to agree on a symptom designation, which is sometimes arbitrated by the maintenance officer - especially if the pilot is inexperienced, or unfamiliar with the equipment. Some supplementary narrative description may accompany the 3-letter code, especially in the case of ambiguous or unusual descriptions.

A carbon copy of the 781 form and one copy of the 76-3 form are sent to maintenance control, where job specialist requirements are allocated. Another copy of the 76-3 is taken to the flight line officer's dispatch area by the debriefer, and given to the flight supervisor. The latter copy is really for the supervisor's information only, since the actual maintenance authorization comes from Maintenance Control. Maintenance Control telephones the flight supervisor at the flight line officer's dispatch area and itemizes the job specialist requirements for all MA-1 maintenance actions. (Maintenance Control completes a form 992). The flight line supervisor allocates all this work among his personnel. The man assigned to a malfunction may (40%) or may not (60%) have been at the cursory inspection. In any case he also receives a copy of the 76-3 form and may also receive a supervisor's recommendation: "replace unit so and so from truck stock."

During his troubleshooting operations, the maintenance man records all of the symptoms which he observes on an AFTO 210 form, and also records each unit he removes (along with reasons for removal) on an AFTO 211 form. These reasons are subsequently coded as "How Mal" codes and are the symptoms received by the shop technician when he troubleshoots the removed units.

In summary, the information available to the man who is involved in the actual maintenance action can come from some or all of the following sources:

(1) Second hand report of the radio communication between the pilot and Maintenance Control.

(2) Direct intercom or face-to-face contact between pilot and flight line technicians during cursory inspection.

(3) Symptoms observed during cursory inspection.

(4) Information recorded during debriefing.

(5) Supervisor's recommendations.

(6) Symptoms observed during maintenance action.

5.   CURRENT SYMPTOM REPORTING AT OTHER BASES

5.1 Selfridge AFB (F-106)

The procedures here are much like those used at Dover,
except as follows. Upon landing, the pilot goes to debriefing
where he is debriefed separately for MA-1 and AFC. He narrates
his complaint to the debriefer who enters three letter codes
and amplifying remarks (if necessary). The sheet is then sent
to maintenance control, then to the shop, and then the repairman.
If an exercise is in progress the pilot may radio the symptom
to maintenance control during taxi-in. Control then radios a
spares truck which meets the aircraft as it parks, and attempts
repairs. The pilot must still go through debriefing.

5.2 MacDill AFB (F-4C)

After each flight the aircrew is interviewed by a representa-
tive of each shop to discuss the various system failures in
detail. The debriefers are usually airmen first class or a staff
sargeant of either five or seven level qualifications. The
debriefers first discuss the symptoms observed by the aircrew to
determine that operator error didn't cause the observed malfunc-
tion. If it is determined that operator error was not the cause,
then specific questions are asked to assist in locating the
trouble more readily.

When the aircrew has been debriefed, the complaints are
transcribed on a special machine and transmitted to maintenance
control. When maintenance control receives the complaints it
assigns a work order and a time to start the repair action to
the appropriate shop. Then Maintenance Control verbally calls
the failure information to the respective shops to effect repair
of the failed system. Rarely will the maintenance men that
actually repair a system discuss a problem with the aircrew that
makes the complaint. If a discussion is held between maintenance
men and aircrew it will only be after repeat writeups on the
same aircraft, same system and same complaint. Then it will
probably be a supervisor rather than the technicians who will
effect the repair.

5.3 Little Rock AFB (B-58)

People from the shops meet the aircraft and get a quick
word from the crew; the latter then report immediately to
debriefing where a code and, if necessary, brief narrative are
taken down by a senior NCO (who has the code book memorized).
One copy of the form (126-1) goes to the shop and one to job
control. The shop gives the job to a repairman who goes out
after job control notifies the shop that it is "their turn" to
effect repairs.

APPENDIX IV

SYMPTOM CODING

1. INTRODUCTION

    This appendix describes how both ASB/4 flight line and
F-106 shop symptoms were coded for machine analysis in this
study.* The coding procedure was derived for this analysis
and as such may be thought of as still in the feasibility stages.

    The problem in coding symptoms is one of developing a
numerical code which will accept all of the vagaries and idio-
syncrasies of unstructured verbatim material and yet not
destroy those characteristics of the symptom which convey the
meaning. Of course one does not know what those characteristics
are until he completes the analysis for which the code is needed.
As a result, all uniqueness has to be coded in such a way that
similar numerical codes imply similar symptom patterns, but so
that individuality is also maintained. (It was decided that
there should be no compromise with the goal of retaining every
distinction available in the data; it is only by retaining
every distinction that one can be sure he has retained the
important distinctions.)

2. ASB/4 SYMPTOMS

    Some idea of the complexity of this task can be seen in the
following list (Table 15) of symptoms reported on one ASB/4
system. (The list is relatively representative of ASB/4 symptoms
in general.)

    Many symptoms (that is many reports) seem to refer to the
same general problem, but each symptom (that is each specific
complaint) is unique.

    Each symptom was separated into its primary grammatical
constituents, defined as (1) Subject or subject phrase, (2)
Description or verb phrase, (3) Subject modifiers, and (4)
Qualifying modifers phrases and Restrictive modifier phrases.
This separation was not rigorous, but is was consistent within
the data and it seems to have been adequate. (Future work
should be well advised to use this basic attack with a more
flexible set of grammatical functions.) Table 16 illustrates
what this decomposition of symptoms actually led to.

---

*For the F-106 flight line data the symptoms which were coded
 during data acquisition and used in this data analysis were
 the 3-letter symptom codes from the 76-3 forms. (See Appendix
 II). Since these codes are being revised by the cognizant
 Air Defense Command Office, they are not included here.

TABLE 15

LIST OF ASB/4 SYMPTOMS

(26 Consecutive Symptoms From System N0004)

1. VRM wavy vertex jumps in off-center 2. H-Cal 10,000 ft low
2. Bomb Bay ring out due
3. Stab leveling plate cracked
4. No nav. lites on forward panel
5. Radar Indicators have excessive interference, spoking, weak returns
6. Actvator arm warn
7. No Sweep
8. Screws missing on map match cover
9. No. 15 second delay in Memory Point
10. 3000 ranging error
11. No Sweep Both Scopes
12. HA will not settle in H-Cal
13. C/I ant, Modulator & RT Unit
14. P. P. Long drives intermittently, operator states that relay 60309 sticks
15. Heading & Az. Mark too bright on 10" scope
16. Broken Wires on Cables leading to Longitude Computer
17. Doubled VRM Close range in Bomb
18. HA 4500 feet in error
19. No Station keeping function in radar
20. Radar goes to recycle then back to radiate in H-Cal and Slant range
21. No. 3 Bracket missing on radome
22. Complete post dock inspection
23. Cross hairs won't track
24. 10" Scope loses sweep intermittantly
25. Double VRM
26. Ringout

TABLE 16

GRAMMATICAL DECOMPOSITION OF SAMPLE SYMPTOMS

Symptom No. (See Table 15)	Subject Modifier	Subject	Verb Phraze	Qualifying and Restrictive Modifying Phrases
17		VRM	Doubled	Close Range in Bomb
25		VRM	Double	
1		VRM	Wavy Jumps	
		Vertex		
4	2.	H-Cal	Low	In off Center 10,000 ft.
12		Nav. lites	no	On forward panel
13	ant, Modulator, & RT Unit	C/I	Will not settle	in H-Cal
16		Wires	Broken	On cables leading to Longitude Computer
18		Ha	in error	
2	Bomb Bay	Ringout	Due	4,500 ft.
26		Ringout		

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In coding these symptoms, each subject-verb phrase of the symptom (that is, each line of type in Table 16) was coded on one IBM card. Preassigned fields on the card were set aside for coded equivalents for (1) the subject modifiers, (2) the subject, (3) the description, (4) up to four modifying phrases, (5) the number of subject-verb phrases (that is the number of cards) required to code the symptom*, and (6) whether or not the basic word pattern of the symptom as it is coded on the IBM card was forward or inverted.

After analyzing each symptom in this manner, the grammatical components were each assigned a four digit code. The codes were assigned in such a way that all grammatically (indeed many typographically) distinct word forms were coded as numerically distinct, but degrees of grammatical similarity were represented by similar degrees of numerical similarity. For example, in the four-digit code assigned to the "subject" position on the IBM card, the first two digits identified the ASB/4 subsystem referred to. The third digit distinguished between separate aspects of that subsystem (if it has separate aspects); the fourth digit varied with ways of referring to this subject and thus identified the specific word or words employed in the symptom. Some actual examples of the subject codes employed can be seen in Table 17.

TABLE 17

SAMPLE SUBJECT CODES

Code	Subject
1800	Warning Lights (Lites)
1820	Coolant Oil Lite (Light)
1821	Coolant Oil Lite (Light)
1822	Coolant Overhead Lite (Light)
1823	Coolant Lite (Light)
1824	Coolant Overheat
1841	ECO Lite (Light)
1842	ECO
1866	Low Limit Lite (Light)
1867	Lower Limit Lite (Light)

---

* Unfortunately, the code lost the order in which these phrases occurred in the symptom. This oversight should be corrected in future language analysis study. Sequential dependencies are undoubtedly significant.

A careful examination of these examples reveals the advantages of this method of coding. First, by selecting the number of fields (i.e. columns on an IBM card) on which to sort, subjects can be grouped together with any desired degree of similarity. If two digit subject codes are used then all subjects referring to "warning lights" will be grouped together and separated from subjects referring to all other ASB-4 subsystems. By adding the third digit to the first two, the discrimination is extended to different kinds of warning lites; if the fourth digit is utilized, the precise language used can be recovered. Other subjects are coded in an equivalent manner. The second advantage in the coding system is that the symptom retains all* of its originality—the information in the reported symptom is retained intact

A similar coding process was used for the other grammatical elements of the reported symptom, again there, the first one or two or three digits referred to the "meaning" of the words in more and more detail and the third and fourth digits referred to the specific detail or form used in that symptom report.

3. F-106 SYMPTOMS

F-106 Shop Symptoms were coded in manner analogous to the one used for the ASB/4 flight line data, but the codes were different, and the number of grammatical components considered was larger. Unfortunately, time was not available for a thorough analysis of these data. It would be interesting to know if this change in the number of grammatical components represents an improvement in the code in terms of its ability to parallel the distribution of information within symptoms.

---

*Except for the failure to code the sequence of phrases in the symptom, which deficiency was corrected when the F-106 shop symptoms were coded.

APPENDIX V

PROGRAMS USED IN THE ANALYSIS

INTRODUCTION

This appendix contains the source programs used in the analysis of data for this study. These programs were used on an IBM 1401 computer with 16000 units of storage and tape drives. These programs are:

1.   Univariate Information Analysis

2.   Analysis of Variance

3.   Phase I of Bivariate Information Analysis

4.   Phase II of Bivariate Information Analysis

Each program is prefaced with an instruction sheet indicating how the program is to be used, after it has been assembled. This sort of form facilitates application of a program with which the user is not familiar---or a program which has become unfamiliar with lack of use. A flow chart of the univariate analysis is provided for those desiring to recode the routine. Since general analysis of variance routines are readily available for larger machines, there was little point in flow charting the routine used here. Supplementary comments on the input and output for the analysis of variance are included. The following paragraphs describe how the input data are sorted before making a Phase II. A description of the Phase II output is also given. No flow chart is provided since anyone wanting to duplicate the bivariate analysis on a larger machine would profit from completely re-constructing the computational process. Consequently, the conventional hand-calculation paradigm has been included to indicate the nature of the calculations being performed in the Phase I and II programs. For more detailed explanation see either Attneave (ref. 5) or Garner (ref. 3).

Sorting the Input Data for Bivariate Information Analysis

The data used in the following example are hypothetical, but they are an adquate representation for illustrating the sorting procedures used to prepare input data for the Phase I routine. To begin with, it is assumed the data have been punched on IBM cards in several fields (groups of card columns used to code a partic-ular element of data). The bivariate analysis routines are concerned with the entries for two such data elements or fields (Table 18).

TABLE 18

RAW DATA

Pilot No.	Symptom
61	RHA
72	FAX
91	FAA
74	RHH
91	FAY
76	FCA
69	RHA
76	RHH
69	FAX
74	RHH
72	FAX
69	FAA
74	RHA
62	FAX
72	RHH
76	FAY
91	RHH
91	RHA
74	RHA
62	FAX
74	FAY
69	RHA
91	RHH

     Consider the condition where one wants to know the extent to which pilot uncertainty and symptom uncertainty are related or overlap (as per Figure 2 in the text). The first step in preparing the input to the Phase I routine is to order the data. Select one of the two variables (data fields), say pilot, and procede to rank order all the data according to the code used (here a numbered coding scheme was used; the analogous procedure is to rank order pilots alphabetically by their last name). Then, for each pilot, it is desireable but not essential to rank the data for him according to the code used for the second variable, here it was symptom (coded with alphabetic characters). The data in Table 19 have been ordered by symptom within pilot (ie. ordered first by pilot, and then within each pilot by the symptom(s) he reported). The program has been written on the assumption that the data will be in this prescribed order. Computations performed will only be correct if this is truly the case. Care must be taken in preparing and checking the input to assure the data are in the proper order prior to running the analysis, or the computations will be in error with no indication that anything has gone wrong.

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TABLE 19

DATA SORTED FOR INPUT TO PHASE I PROGRAM

Pilot No.	Symptom
61	RHA
62	FAX
62	FAX
69	FAA
69	FAX
69	RHA
69	RHA
72	FAX
72	FAX
72	RHH
74	FAY
74	RHA
74	RHA
74	RHH
74	RHH
76	FAY
76	FCA
76	RHH
91	FAA
91	FAY
91	RHA
91	RHH
91	RHH

The Phase I routine simply takes a frequency count of the unique data pairs (specific pilot-symptom code combinations) that occur in the data deck being run. This frequency count information is punched out on cards in the same order as the first variable (pilot here). These cards (Table 20) are subsequently used as the input deck for the Phase II routine. The output of that analysis is shown in Table 21,a. Table 21,b provides similar output for the case where the two variables are reversed, repeating the above procedures. This merely entails an analogous ranking, but this time pilots are ranked within symptom.

Given the output from these two Phase II passes, it is possible to compute the bivariate uncertainty ($U_{S:P}$) and the bivariate constraint ($C_{S:P}$ or $C_{P:S}$) as shown in section 3.1.1.2. The conventional matrix format, notation, formulae, and computations used for manual calculation of U_S, U_P, and $U_{S:P}$ are given in Table 22.

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TABLE 20

DATA COUNTED (OUTPUT OF PHASE I PROGRAM RUN)

Pilot No.	Symptom	Count
61	RHA	1
62	FAX	2
69	FAA	1
69	FAX	1
69	RHA	2
72	FAX	2
72	RHH	1
74	FAY	1
74	RHA	2
74	RHH	2
76	FAY	1
76	FCA	1
76	RHH	1
91	FAA	1
91	FAY	1
91	RHA	1
91	RHH	2

TABLE 21

PHASE II OUTPUT

a.) Information Calculated

Pilot No.	Information
61	0.0000
62	0.0000
69	1.5000
72	0.9183
74	1.5219
76	1.5850
91	1.9219

Uncertainty in Pilot (U_P): 2.6658

Total Uncertainty (U_T): 4.0018

b.) Information Calculated

Symptom	Information
FAA	1.0000
FAX	1.5218
FAY	1.5850
FCA	0.0000
RHA	1.9183
RHH	1.9183

Uncertainty in Symptom (U_S): 2.3764

Total Uncertainty (U_T): 4.0018

TABLE 22

MATRIX DERIVED FROM THE RAW DATA SHOWING
THE JOINT FREQUENCY OF PILOT-SYMPTOM COMBINATIONS

Since $p_{ij} = n_{ij} / N$, it follows that: $\log_2 p_{ij} = \log_2 (n_{ij} / N)$

$$\text{or} = \log_2 n_{ij} - \log_2 N$$

Hence, $P_{ij} \log_2 p_{ij} = (n_{ij} / N) \log_2 n_{ij} - (n_{ij} / N) \log_2 N$

Therefore, $-\sum_{i,j} p_{ij} \log_2 p_{ij} = -\sum_{i,j} (n_{ij} / N) \log_2 n_{ij} + \sum_{i,j} (n_{ij} / N) \log_2 N$

Since, $\sum_{i,j} n_{ij} = N$, the above equation can be more conveniently

arranged:

$$-\sum p_{ij} \log_2 p_{ij} = \log_2 N - 1/N \sum n_{ij} \log_2 n_{ij}$$

Pilot	Symptom: FAA	FAX	FAY	FCA	RHA	RHH	$\sum_{i=1}^{i=6} n_{ij} =$
61	0	0	0	0	1	0	1
62	0	2	0	0	0	0	2
69	1	1	0	0	2	0	4
72	0	2	0	0	0	1	3
74	0	0	1	0	2	2	5
76	0	0	1	1	0	1	3
91	1	0	1	0	1	2	5
$\sum_{i=1}^{i=7} n_{ij}$	2	5	3	1	6	6	$23 = \sum_{i=1}^{i=7} \sum_{j=1}^{j=6} n_{ij} = N$

$$U_p = \log_2 N - 1/N \sum_{j=1}^{j=6} \left[\left(\sum_{i=1}^{i=7} n_{ij} \right) \log_2 \left(\sum_{i=1}^{i=7} n_{ij} \right) \right]$$

$$U_s = \log_2 N - 1/N \sum_{i=1}^{i=7} \left[\left(\sum_{i=1}^{i=6} n_{ij} \right) \log_2 \left(\sum_{i=1}^{i=6} n_{ij} \right) \right]$$

$$U_{sp} = \log_2 N - 1/N \sum_{i=1}^{i=7} \sum_{j=1}^{j=6} \left[n_{ij} \log_2 n_{ij} \right]$$

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IDENTIFICATION

Univariate Information   *523-01-2*
　　　　　　　　　Program Title   File Number

Uncertainty 'n Units Reported   *Leuba*   *5/16/66*
　　　　　　Purpose   Programmer   Date

1401   *16K*   *Cards*   *Fortran II*   *Yes*
Machine   Size   Tape/Cards   Language   SS Zero

INPUT

   1. Program Object Deck

   2. Header Cards　　　*None*　　　　　Format　　　　　p. ____

C
Y   3. Data, Serialized　　　—　　　⟶ Format　　*①*　　p. *1*
C
L   4. Control Card　　*Blank*　　　　Format　　　　　p. ____
E
S   5. Data, Serialized　　　—　　　⟶ Format　　*①*　　p. *1*

   6. Control Card　　*Blank*　　　　Format　　　　　p. ____

   7. End Card　　　*None*　　　　　Format　　　　　p. ____

SS　　Ⓐ　　　B　　　C　　　D　　　E　　　F　　　G

____　____　____　____　____　____　____

OUTPUT

   Punch　　　*None*　　　　　　　Format　　　　　p. ____

   Print *Average Uncertainty across cycles &* *Data list, Unit table, & Uncertainty per cycle*　Attached as p. ____

RESTRICTIONS

   1. Data Content: See Format _____ p ____ (undesignated - no limits;
      A - alpha only; # - numeric only; O - no blanks; X - no symbols)

   2. Sample Size　*Do not use more than 125 possible units*

   3. Computational Assumptions　*All mentioned units are equally likely causes of failure*

   4. Computer Assumptions

ATTACHMENTS

   FORMAT FORM/CODE TRANSLATION/LISTING OF SOURCE DECK/SAMPLE OUTPUT

---

* This program can be utilized by route application of the instructions on
page one. Additional material is provided to facilitate modification.

AD-A054 447   ARINC RESEARCH CORP   ANNAPOLIS MD   F/G 15/5
               INFORMATION TRANSMISSION IN OPERATOR REPORTS OF EQUIPMENT MALFU--ETC(U)
               MAY 67   H R LEUBA   AF 33(615)-3383
UNCLASSIFIED   523-01-1-783   NL

2 OF 2
ADA
054447

END
DATE
FILMED
6-78
DDC

SYS#	REP#	M/C	ADJ	SUBJ	DESC	MOD1	MOD2	MISC.	# OF Phrs	PREP TIME	MALF VER	FAULT LOC

1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10

① 10 20 30 40

INPUT

| PART PROC. | RUR TIME | MALF AQ Delay | 3 5 7 | UNIT | W T | UNIT | W T | UNIT | W T | M V | % | RANDOM NUMBER | WORK ORDER |

1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10

IDENTIFICATION 50 60 70 80

1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10

② 10 20 30 40

CONTROL

1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10

IDENTIFICATION 50 60 70 80

1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10

③ 10 20 30 40

1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10

IDENTIFICATION 50 60 70 80

1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10

④ 10 20 30 40

1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10

IDENTIFICATION 50 60 70 80

1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10

⑤ 10 20 30 40

1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10

IDENTIFICATION 50 89 60 70 80

Page	Format	Column	Entry	Interpretation
1	①	1-7		IDENTIFICATION
		8-32		SYMPTOM
		33-51		MAINTENANCE TIMES
		52-54		NUMBER OF MAINTENANCE MEN
		55-57 } 59-61 } 63-65 }		UNIT DESIGNATION (USE CODED NUMBER ≤ 125)
		58 } 62 } 66 }		FAILURE WEIGHT 6 if only one "unit" is involved 3 if only two units are involved 2 if three units are involved
		67		MALFUNCTION VERIFICATION
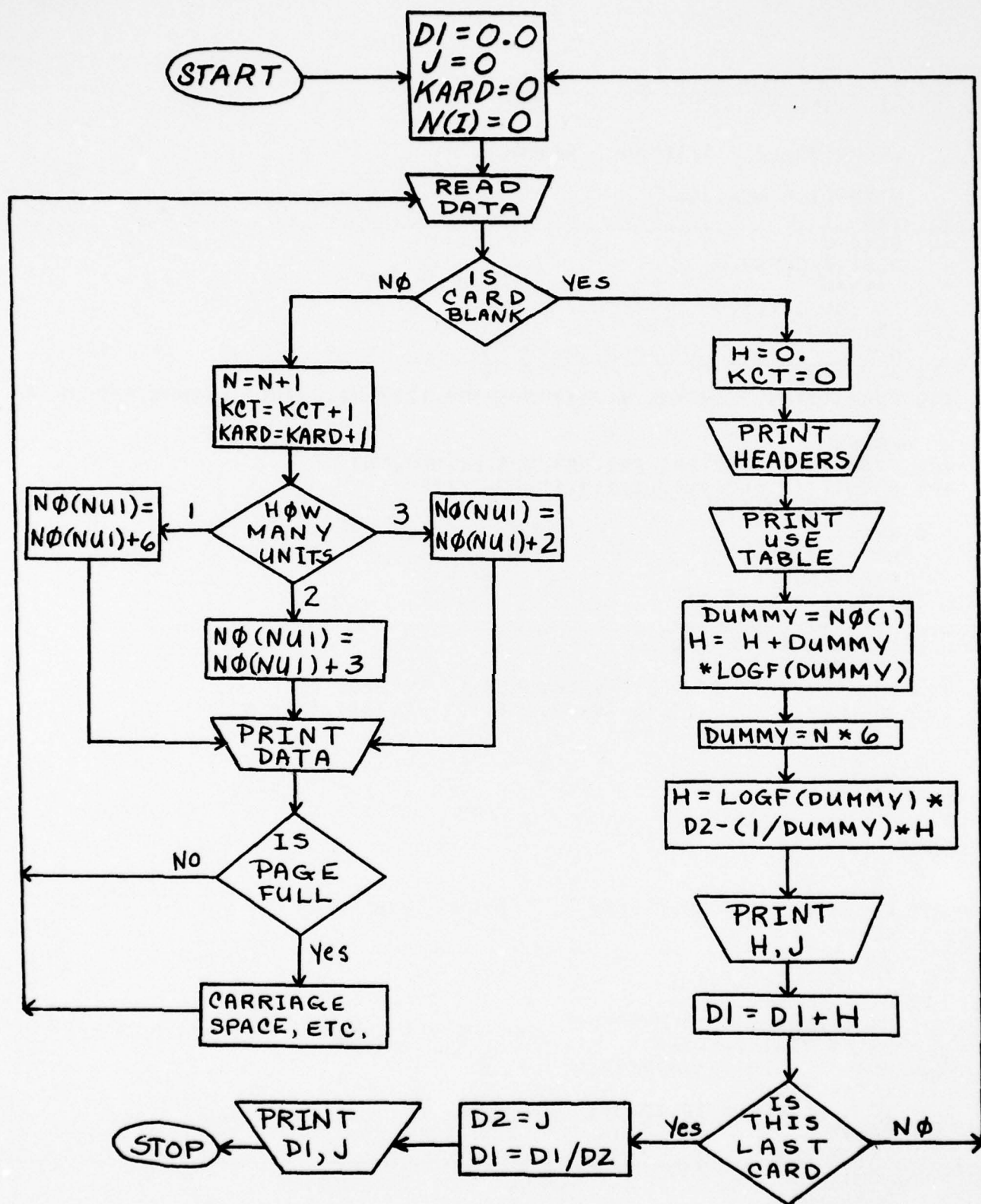
FLOW CHART FOR UNIVARIATE ANALYSIS

91

1266

```
      PARAMI9I   09PS A
C
C       LEURA NO. 2    5/16/66     523-01
C
        DIMENSION NO%125¤
        J#0
        D1#0.0
        D2#1./LOGF%2.¤
        KARD#0
   50 DO 105 I#1,125
  105 NO%I¤#0
        N#0
   51 PRINT 700
  700 FORMAT%1H1,2X6HSYS. #,23X7HSYMPTOM,12X2HU1,2X2HC1,4X2HU2,4X2HU3,//
     1//¤
        KCT#0
  106 READ 100,NTEST,PR1,PR2,PR3,NU1,L1,NU2,NU3
  100 FORMAT%I3,4X2A9,A7,22XI3,I1,I3,1XI3 ¤
        IF%NTEST¤7,7,8
    8 N#N&1
        KCT#KCT&1
        KARD#KARD&1
        IF%L1-3¤ 9,10,11
    9 NO%NU1¤#NO%NU1¤&2
        NO%NU2¤#NO%NU2¤&2
        NO%NU3¤#NO%NU3¤&2
  110 PRINT 701,NTEST,PR1,PR2,PR3,NU1,L1,NU2,NU3
  701 FORMAT%1H ,3XI3,3XA9,A9,A7,15XI3,3XI1,3XI3,3XI3 ¤
        IF%KCT-45¤   106,106,51
   10 NO%NU1¤#NO%NU1¤&3
        NO%NU2¤#NO%NU2¤&3
        GO TO 110
   11 NO%NU1¤#NO%NU1¤&6
        GO TO 110
    7 H#0.
        PRINT 705
  705 FORMAT%1H1,20HUNIT CODE       COUNT ,//¤
        KCT#0
        DO 12 I#1,125
        IF%NO%I¤¤12,12,13
   13 DUMMY#NO%I¤
        H#H&DUMMY*LOGF%DUMMY¤*D2
        PRINT 706, I,NO%I¤
  706 FORMAT % 1H ,4XI3,9XI5 ¤
        KCT#KCT&1
        IF % KCT-45 ¤ 12,12,901
  901 KCT#0
        PRINT 705
   12 CONTINUE
        DUMMY#N*6
        H#LOGF%DUMMY¤*D2-1./DUMMY*H
        J#J&1
        PRINT 702,N,H,J
  702 FORMAT%1H0,13HCARD COUNT - ,I5,15H  INFORMATION  ,F10.4,15H  SYMPT
```

```
      1OM NO.    ,I3,//□
      D1#D1&H
      IF%SENSE SWITCH 0□ 52,50
   52 D2#J
      D1#D1/D2
      PRINT 704,KARD,D1,J
  704 FORMAT%1H1,13HCARD COUNT - ,I5,15H  INFORMATION  ,F10.4,15H  SYMPT
      1OM NO.    ,I3,//□
      STOP 999
      END
```

IDENTIFICATION

ANALYSIS ⁀ VARIANCE SEARCH   *523-01-3*
Program Title   File Number

9 ANOVA 'N TIME & MEN   *LEUBA*   *5/21/66*
Purpose   Programmer   Date

1401   *16K*   *CARDS*   *FORTRAN II*   *YES*
Machine   Size   Tape/Cards   Language   SS Zero

INPUT - SAME AS PROGRAM 523-01-2 ←

1. Program Object Deck

2. Header Cards _____ *NONE* _____ Format _____ p. _____

C
Y   3. Data, Serialized _____ — _____→ Format ① p. 1
C
L   4. Control Card _____ *BLANK* _____ Format _____ p. _____
E
S   5. Data, Serialized _____ — _____→ Format ① p. 1

6. Control Card _____ *BLANK* _____ Format _____ p. _____

7. End Card _____ *NONE* _____ Format _____ p. _____

SS   Ⓐ   B   C   D   E   F   G

_____ _____ _____ _____ _____ _____ _____

OUTPUT

Punch _____ *NONE* _____ Format _____ p. _____
ANOVA across cycles for each of 9 variables of time and no. of men
Print *Data list, Means & Sigmas for each cycle* _____ Attached as p. _____

RESTRICTIONS

1. Data Content: See Format _____ p _____ (undesignated - no limits;
   A - alpha only; # - numeric only; 0 - no blanks; X - no symbols)

2. Sample Size

3. Computational Assumptions *Intermediate variances estimated over N*
                              rather than N-1

4. Computer Assumptions
        Do not get two blank cards in a row

ATTACHMENTS

FORMAT FORM/CODE TRANSLATION/LISTING OF SOURCE DECK/SAMPLE OUTPUT

* This program can be utilized by route application of the instructions on
  page one. Additional material is provided to facilitate modification.

① SYS# | RFP# | N/S | ADJ | SUBJ | DESC | MOD 1 | MOD 2 | MISC | # of Phrs | PREP TIME | MALF VER | FAULT LOC

INPUT
IDENTIFICATION

PART PROC | RER TIME | MALF AD. DELAY | 3 5 7 | UNIT | WT | UNIT | WT | UNIT | WT MV | % | RANDOM NUMBER | WORK ORDER

②

CONTROL
IDENTIFICATION

③

IDENTIFICATION

④

IDENTIFICATION

⑤

IDENTIFICATION

95

Page	Format	Column	Entry	Interpretation.
1	①	1-7		IDENTIFICATION
		8-32		SYMPTOM
		33-51		MAINTENANCE TIMES (missing data punched as minus 1 — and not counted in calculations)
		52-54		NUMBER OF MAINT. MEN
		55-66		UNITS
		67		MALFUNCTION VERIFICATION

PROCEDURES FOR USING THE ANALYSIS
OF VARIANCE PROGRAM

1. Prepare input data in the same form as for the Univariate Analysis (same deck can be used).

2. Stack the input deck behind the program deck prepared according to the following program listing.

OUTPUT:

a) a list of the input data

b) the mean and standard deviation for each symptom for each variable*

c) a summary ANOVA table for each variable

NOTE:

a) the standard deviation is a biased estimate, uncorrected for degrees of freedom; this permits a simplification in the program by assuring that a zero denominator does not result in those cases where the "variable" was only one score, since in that case N-1=0. If an unbiased estimate were required, the program must be appropriately modified.

b) negative data in the output listing simply indicates the value was missing, and the point is not counted.

*c) variables analyzed include: preparation time, malfunction verification time, fault location time, part procurement time, repair time, administrative delay time, number of three level technicians, number of five level technicians, and number of seven level technicians.

```
PARAMI9I   09PS A
C
C      LEUBA # 3
C
       DIMENSION CSUM%9¤,CX2%9¤,TOTAL%9¤,TSS%9¤,X%9¤,SIG%9¤,CSS%9¤,CNO%9¤
      1,TLDF%9¤,AV%9¤
       DO 15 I#1,9
       TLDF%I¤#0.0
       TOTAL%I¤#0.0
       TSS%I¤#0.0
    15 CSS%I¤#0.0
       CDF#0.0
    10 DO 16 I#1,9
       CNO%I¤#0.0
       CSUM%I¤#0.0
    16 CX2%I¤#0.0
     1 KOUNT#0
       PRINT 200
   200 FORMAT%1H1,2X5HIDENT,12X7HSYMPTOM,13X4HPREP,3X4HM.V.,3X4HF.L.,3X4H
      1P.P.,3X4HREP.,3X5HM.AD.,3X4HNO.3,3X4HNO.5,3X4HNO.7,///¤
     5 READ 100,IT,D1,D2,D3,D4,%X%I¤,I#1,9¤
   100 FORMAT% I3,A4,2A8,A9,5F3.2,F4.2,3F1.0 ¤
       IF%IT¤ 50,50,17
    17 PRINT 201,IT,D1,D2,D3,D4,%X%I¤,I#1,9¤
   201 FORMAT%1H ,1XI3,A4,2X2A8,A9,1X5%3XF4.2¤,3XF5.2,3%3XF4.1¤¤
       KOUNT#KOUNT&1
       DO 18 I#1,9
       IF%X%I¤¤ 18,190,191
   191 CSUM%I¤#CSUM%I¤&X%I¤
       CX2%I¤#CX2%I¤&X%I¤*X%I¤
   190 CNO%I¤#CNO%I¤&1.
    18 CONTINUE
       IF%KOUNT-45¤ 5,1,1
    50 CDF#CDF&1.
       DO 19 I#1,9
       TLDF%I¤#TLDF%I¤&CNO%I¤
       TOTAL%I¤#TOTAL%I¤&CSUM%I¤
       TSS%I¤#TSS%I¤&CX2%I¤
       AV%I¤#CSUM%I¤/CNO%I¤
       SIG%I¤#SQRTF%%CX2%I¤-%CSUM%I¤*CSUM%I¤/CNO%I¤¤¤/CNO%I¤¤
    19 CSS%I¤#CSS%I¤&CSUM%I¤*CSUM%I¤/CNO%I¤
       PRINT 202,%AV%I¤,I#1,9¤
   202 FORMAT%1H0,25X7HAVERAGE,7X5%F4.2,3X¤,F5.2,3%2XF5.2¤¤
       PRINT 203,%SIG%I¤,I#1,9¤
   203 FORMAT%1H ,25X5HSIGMA,6X5%2XF5.2 ¤,3XF5.2,  3%2XF5.2¤¤
       PRINT 607,%CNO%I¤,I#1,9¤
   607 FORMAT%1H ,25X1HN,12X5%F5.0,2X¤,F6.0,3%2XF5.0¤¤
       IF%SENSE SWITCH 0 ¤ 75,10
    75 DO 20 I#1,9
       PRINT 204
   204 FORMAT%1H1,10X26HANOVA WITH UNEQUAL COLUMNS,///¤
       GO TO %21,22,23,24,25,26,27,28,29¤,I
    21 PRINT 301
   301 FORMAT%1H ,13X20H  PREPARATION TIME  ,//¤
```

```
         GO TO 30
   22 PRINT 302
  302 FORMAT%1H ,13X20H  MALF. VER. TIME    ,//□
         GO TO 30
   23 PRINT 303
  303 FORMAT%1H ,13X20H  FAULT LOC. TIME    ,//□
         GO TO 30
   24 PRINT 304
  304 FORMAT%1H ,13X20H  PART PROC. TIME    ,//□
         GO TO 30
   25 PRINT 305
  305 FORMAT%1H ,13X20H     REPAIR TIME     ,//□
         GO TO 30
   26 PRINT 306
  306 FORMAT%1H ,13X20H MALF. ADMIN. DELAY ,//□
         GO TO 30
   27 PRINT 307
  307 FORMAT%1H ,13X20H NO. OF 3 LEVEL MEN ,//□
         GO TO 30
   28 PRINT 308
  308 FORMAT%1H ,13X20H NO. OF 5 LEVEL MEN ,//□
         GO TO 30
   29 PRINT 309
  309 FORMAT%1H ,13X20H NO. OF 7 LEVEL MEN ,//□
   30 PRINT 310
  310 FORMAT%1H ,10X26HANALYSIS OF VARIANCE TABLE,///3X6HSOURCE,8X2HSS,
       17X2HDF,7X2HMS,9X1HF□
      CF#TOTAL%I□*TOTAL%I□/TLDF%I□
      A#CSS%I□-CF
      B#CDF-1.
      C#A/B
      H#TSS%I□-CF
      AI#TLDF-1.
      E#H-A
      F#AI-B
      G#E/F
      D#C/G
      PRINT 311,A,B,C,D,E,F,G,H,AI
  311 FORMAT%1H0,2X6HCOLUMN,3XF11.5,1XF5.0,2XF10.5,2XF6.2/3X6HERROR ,3XF
      111.5,1XF5.0,2XF10.5/3X6HTOTAL ,3XF11.5,1XF5.0□
   20 CONTINUE
      STOP 777
      END
```

IDENTIFICATION

BIVARIATE ANALYSIS I   _518-01-1_
            Program Title   File Number

READ DATA MATRIX ITEM BY ITEM
PUNCH IT CELL BY CELL   _THOMAS_   _617/66_
            Purpose   Programmer   Date

_1401_   _16K_   _CARDS_   _AUTOCODER_   _N/A_
Machine   Size   Tape/Cards   Language   SS Zero

INPUT

1. Program Object Deck

2. Header Cards   _VARIABLE FORMAT_   Format ___①___ p. _1_

3. Data, Serialized _A WITHIN B_ ⟶ Format ___②___ p. _1_

4. Control Card _____NONE_____   Format _____ p. ____

5. ~~Data, Serialized~~ ⟶ ~~Format~~ ~~p.~~

6. ~~Control Card~~ ~~Format~~ ~~p.~~

7. End Card _____BLANK_____   Format _____ p. ____

SS   A   B   C   D   E   F   G
___   ___   ___   ___   ___   ___   ___   ___

OUTPUT

Punch _MATRIX CELL BY CELL &_   Format ___③___ p. _1_
      CELL COUNT CARD   ④   _1_

Print _____   Attached as p. _____

RESTRICTIONS

1. Data Content: See Format _____ p ____ (undesignated - no limits;
      A - alpha only; # - numeric only; O - no blanks; X - no symbols)

2. Sample Size

3. Computational Assumptions _Neither variable A nor B may exceed 5_
                              (consecutive) fields (card columns)

4. Computer Assumptions

Data field in last data card must not be blank

ATTACHMENTS

FORMAT FORM/CODE TRANSLATION/LISTING OF SOURCE DECK/SAMPLE OUTPUT

* This program can be utilized by route application of the instructions on
  page one. Additional material is provided to facilitate modification.

①
VAR A   VAR B

1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10
10   20   30   40

1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10

HEADER
IDENTIFICATION   50   60   70   80

②
NO RESTRICTIONS

1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10
10   20   30   40

1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10

DATA
IDENTIFICATION   50   60   70   80

③
ATEST   BTEST   No of Cases

1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10
10   20   30   40

1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10

OUTPUT
IDENTIFICATION   50   60   70   80

④
COUNT

1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10
10   20   30   40

1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10

OUTPUT
IDENTIFICATION   50   60   70   80

⑤
1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10
10   20   30   40

1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10 | 1 2 3 4 5 6 7 8 9 10

IDENTIFICATION   50   101   60   70   80

Page	Format	Column	Entry	Interpretation.
1	①	2-3	VARA	STARTING FIELD (FORMAT ②) FOR VARIABLE A
		4-5	VARA	ENDING FIELD FOR VARIABLE A
		10-11	VARB	STARTING FIELD FOR VARIABLE B
		12-13	VARB	ENDING FIELD FOR VARIABLE B
1	②			DO NOT EXCEED FIVE SPACES PER VARIABLE
1	③	8-12		PUNCH: VARIABLE A FROM FORMAT ②
		13-17		PUNCH: VARIABLE B FROM FORMAT ②
		23-26		PUNCH: No OF CASES IN CELL IDENTIFIED
1	④	1-5		No OF CELLS IN MATRIX (EMPTY CELLS NOT COUNTED)

```
01010              JOB            LEUBA     518-01    7/8/66
01020              CTL   6611
01030BEGIN         SW    1,5
01040              SW    9,13
01050              R
01060              MCW   3,SET&3
01070              MCW   11,SET&6
01080              MCW   7,COR1&3
01090              MCW   7,COR3&3
01100              MCW   15,COR2&3
01110              MCW   15,COR4&3
01120              CS    80
01130SET           SW    0,0
01140              R
01150RET           LCA   @000@,IR1
01160COR1          LCA   0,TEST1
01170COR2          LCA   0,TEST2
01180COR3          C     0,TEST1
01190              BU    PUNCHO
01200COR4          C     0,TEST2
01210              BU    PUNCHO
01220              MA    @001@,IR1
01230              R
01240              B     COR3
01250PUNCHO        MCW   TEST1,112
02010              MCW   TEST2,119
02020              MCW   IR1,126
02030              P
02040              BLC   ENDJOB              LAST CARD MUST BE BLANK
02050              B     RET
02060ENDJOB        CC    1
02070              LCA   @END OF JOB @, 215
02080              W
02090              CC    1
02100              H
02110TEST1         DCW   #50
02120TEST2         DCW   #50
02130IR1           EQU   89
02140              END   BEGIN
```

103

IDENTIFICATION

BIVARIATE ANALYSIS II   518-01-2

Program Title   File Number

READ DATA MATRIX CELL BY CELL
CALCULATE ROW U & TOTAL U   *LEUBA*   6/7/66

Purpose   Programmer   Date

1401   *16K*   *CARDS*   *FORTRAN II*   *YES*

Machine   Size   Tape/Cards   Language   SS Zero

INPUT   *OUTPUT OF 518-01-1*

1. Program Object Deck   *& TABLE OF VALUES*   ①

2. Header Cards   *NONE*   Format _____ p. _____

3. Data, Serialized   —   → Format   ②   p. _____

4. Control Card   *NONE*   Format _____ p. _____

5. Data, Serialized   → Format   p.

6. Control Card   Format   p.

7. End Card   *BLANK*   Format _____ p. _____

SS   Ⓐ   B   C   D   E   F   G

OUTPUT   *ROW SUM & INFORMATION — EACH ROW*   ③

Punch *TOTAL SUM & TOTAL INFORMATION*   Format   ④ & ⑤ p. *1*

Print   *SAME*   Attached as p. _____

RESTRICTIONS

1. Data Content: See Format _____ p ____ (undesignated - no limits;
   A - alpha only; # - numeric only; 0 - no blanks; X - no symbols)

2. Sample Size

3. Computational Assumptions   *Read in Log n   n ≤ 100*

4. Computer Assumptions

ATTACHMENTS

FORMAT FORM/CODE TRANSLATION/LISTING OF SOURCE DECK/SAMPLE OUTPUT

* This program can be utilized by route application of the instructions on
page one. Additional material is provided to facilitate modification.

1   **2**   **...**

1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
10	20	30	40

①

TABLE DENTIFICATION

1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
50	60	70	80

ATEST   BTEST   No OF Cases

1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
10	20	30	40

②

INPUT IDENTIFICATION

1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
50	60	70	80

ATEST   ROW NO   ROW SUM

ROW D   ROW NO   ROW SUM

1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
10	20	30	40

③

ROW INFORMATION

INFO

OUTPUT IDENTIFICATION

1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
50	60	70	80

SUM

1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
10	20	30	40

④

OUTPUT IDENTIFICATION

1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
50	60	70	80

TOTAL No ROWS

1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
10	20	30	40

⑤

OUTPUT IDENTIFICATION

1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10	1 2 3 4 5 6 7 8 9 10
50	60	70	80

Page	Format	Column	Entry	Interpretation
1	①			Table of Log (n) n = 1,100 , 5 values per card
	②			Output of 518-01-1
	③			Row Sums & Info
	④	1-9		Total Number of Observations
	⑤	1-3		Total Number of Rows in Matrix

```
PARAMI910808PS A
C        PROGRAM TO COMPUTE JOINT UNCERTAINTY -- PHASE II
C            LEUBA, WO 518-01, JUNE 7, 1966
C               INPUT IS OUTPUT OF PHASE I
C                  NO HEADER
C                  NO SSW, NO TAPE, PRINT & PUNCH ON
C                  END DATA WITH A BLANK CARD
         NROW  # 0
         RSUM  # 0.
         RINFO # 0.
         TSUM  # 0.
         TINFO # 0.
         VINFO # 0.
    1 FORMAT %7XA5,10XF4.0 ¤
    2 FORMAT%7HROW D   ,A5,3X7HROW NO ,I4,2X8HROW SUM ,F5.0,2X6HINFO  ,
      1F9.5¤
    3 FORMAT%1H ,3XA5,4XI4,2XF6.0,2XF9.5¤
    4 FORMAT   %1H-,2X,17HINFO IN MARGINALS,6X,F9.5¤
    5 FORMAT   %1H-,2X,17HTOTAL INFORMATION,6X,F9.5¤
    8 FORMAT %F9.0¤
    6 FORMAT %1H1,3X,29HROW D    ROW NO   ROW SUM   INFO¤
    7 FORMAT %I3¤
         PRINT 6
         D2 # 1./LOGF%2.¤
         READ 1,ATEST,DATA
   70 RSUM # RSUM & DATA
         RINFO # RINFO & DATA*LOGF%DATA¤
         DUMMY # ATEST
   30 READ 1,ATEST,DATA
         DOMMY#ATEST
         IF%DOMMY-DUMMY¤ 50,60,50
   60 RINFO # RINFO & DATA*LOGF%DATA¤
         RSUM   # RSUM & DATA
         GO TO 30
   50 TSUM # TSUM & RSUM
         NROW # NROW & 1
         TINFO # TINFO & RINFO
         VINFO # VINFO & RSUM*LOGF%RSUM¤
         RINFO # D2*%LOGF%RSUM¤&%-1./RSUM¤*RINFO¤
         PUNCH 2,DUMMY,NROW,RSUM,RINFO
         PRINT 3,DUMMY,NROW,RSUM,RINFO
         RSUM # 0.
         RINFO# 0.
         IF%SENSE SWITCH 0¤ 20,70
   20 VINFO # D2*%LOGF%TSUM¤&%-1./TSUM¤*VINFO¤
         PRINT 4, VINFO
         TINFO # D2*%LOGF%TSUM¤&%-1./TSUM¤*TINFO¤
         PRINT 5, TINFO
         PUNCH  8, TSUM
         PUNCH  7, NROW
         END
```

APPENDIX VI

LIST OF CALCULATIONS PERFORMED

A. Univariate Uncertainty Calculations - ASB-4

    1. Intermittent vs. stable symptoms

    2. No. of Phrases

    3. Malfunction number for 1 card events

    4. Malfunction number for multicard events

    5. 2-digit subject

    6. 2-digit description

    7. Mood

    8. Modifiers

    9. One card events

    10. Number of cards per event

    11. Operator complaints without modifiers

    12. Operator complaints by 2-digit modifiers

    13. Subject by description

    14. Carefully sorted job

    15. Job as 2-digit subject

B. Analyses of Variance - ASB/4

    1. Intermittent vs. stable symptoms

    2. Preventive maintenance by subject

    3. Mood

    4. Malfunction number by number of cards/events

    5. 2-digit description

    6. Job as 2-digit subject

    7. Carefully sorted job

    8. Job by maintenance men profile

C. Bivariate Uncertainty Calculations - ASB/4

1. Subject by modifier
2. 4-digit description by second modifier
3. Subject by adjective
4. Subject by maintenance men profile
5. Subject by malfunction number
6. Description by adjective
7. Maintenance men profile by malfunction verification
8. Subject by description

D. Bivariate Information Calculations F-106

1. Pilot vs. A/C No. 1965 SQD 95 (Dover)
2. Pilot vs symptom
3. Maintenance man vs symptom (Dover only)
4. A/C vs symptom   (Dover only)
5. Pilot vs A/C
6. Symptom vs NFS
7. SQD vs Symptom
8. Symptom vs unit
9. Verif vs symptom
10. (Method of TS & Maint. Concept) vs symptom
11. (Maint Process (3 col field) vs NFS
12. Symptom vs Downtime
13. Date vs symptom
14. Verif vs NFS
15. Pilot vs verif.
16. NFS vs pilot
17. How Mal vs Man
18. Unit vs How Mal
19. NFS vs Unit
20. How Mal vs NFS
21. A/C vs symptom   (Selfridge only)
22. Pilot vs symptom (Selfridge only)

23. Maint. concept vs T.S. method (Selfridge only)
24. Maint. concept vs. T.S. Meth. (Selfridge only)
25. A/C vs date
26. Pilot vs date
27. Man vs. verif.
28. (Maint. concept & T.S. meth.)
29. Verif. vs (maint. concept & T.S. meth.)
30. Pilot & symptom vs. Verif.
31. Pilot & symptom vs A/C
32. A/C vs verif.
33. Base vs verif.
34. Mission success vs verif.
35. Malf. no. vs verif.
36. Severity vs. verif.
37. Action taken vs. verif.
38. Concept vs. verif.
39. T.S. vs. verif.
40. Downtime vs. verif.
41. NFS vs downtime
42. NFS vs maint. man
43. Maint. man vs T.S. Meth.
44. T.S. Meth vs (symptom/Unit)
45. (Symptom/unit) vs NFS
46. NFS vs Maint. concept
47. Maint concept vs symptom
48. Symptom vs base
49. Symptom vs (base and AC)
50. (Base & AC) vs NFS
51. NFS vs T.S. Meth.
52. T.S. meth vs How Mal
53. How Mal vs symptom
54. Report no. vs symptom
55. How Mal vs symptom
56. Pilot vs How Mal

57. Downtime vs pilot
58. Unit vs Downtime
59. When discovered vs unit
60. Downtime vs when discovered
61. Downtime vs meth. of T.S.
62. Meth of T.S. vs Symptom
63. Symptom vs Maint. concept
64. Downtime vs maint. concept
65. Unit vs pilot
66. A/C vs Unit
67. Mission success vs severity
68. Man vs NFS   (Dover only)
69. Meth. of T.S. vs man   "   "
70. Downtime vs meth of T.S.   "   "
71. Man vs Downtime   "   "
72. Man 2 vs Man 1   "   "
73. Downtime vs Man 2   "   "
74. Unit vs downtime   "   "
75. Shop vs Unit   "   "
76. Symptom vs Shop   "   "
77. Downtime vs symptom   "   "
78. How mal vs downtime   "   "
79. Shop vs How Mal   "   "
80. Man vs shop   "   "
81. Method of T.S. vs man   "   "
82. Shop vs method of T.S.   "   "
83. Maint. concept vs shop   "   "
84. Downtime vs maint. concept   "   "
85. Pilot vs downtime   "   "
86. (Symptom & Unit) vs pilot   "   "
87. Downtime vs (Symptom & unit)   "   "
88. (Symptom & Man) vs downtime   "   "
89. Concept vs man   "   "
90. How Mal vs Maint. Concept   "   "

91. Pilot vs symptom   (Dover only)

92. A/C vs (pilot vs symptom)   "   "

93. A/C & Pilot vs symptom   "   "

94. Unit & How Mal vs man   "   "

95. Concept vs meth of T.S.

96. NFS vs (Meth & concept)

97. Symptom vs method of T.S.

98. A/C vs Symptom

99. Base vs A/C

100. Pilot vs NFS

101. Pilot & symptom vs NFS

102. Pilot & symptom & unit vs NFS

103. Unit vs How Mal

104. Unit & meth. of T.S. vs How Mal

105. Unit & Meth. of T.S. & pilot vs How Mal

106. Symptom vs downtime

107. Symptom & Unit vs downtime

108. Symptom & Unit & Meth of T.S. vs Downtime

109. Symptom & Unit & Method of T.S. & Maint. concept
       vs Downtime

110. Symptom vs unit

111. Symptom & Pilot vs Unit

112. Symptom & pilot & Meth of T.S. vs unit

113. Symptom vs verif.

114. Pilot & symptom vs Verif.

115. Pilot & symptom & maint. concept) vs verif.

116. Unit vs bench check (RHH Symptoms only)

2. X^2 analysis of F-106 shop symptoms

    a. No. words

    b. No. phrases

    c. Presence of word denoting intermittent

    d. Presence of qualifying phrase

e. Number of nominalizations

f. Presence of negative

g. Position and presence of subject

h. Position and presence of object

i. Position and presence of verb

j. Position and presence of prepositional phrase

k. Position and presence of modifiers

3. Correlation analysis for selected ASB/4 symptom

  a. Information content versus trouble-shooting time.

  b. Information content versus probability of malfunction
      verification

4. Correlation analysis for selected F-106 symptoms

  a. Information content versus probability of malfunction
      verification

  b. Information content versus number of units removed
      per action.

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13. ABSTRACT

This study established the feasibility of using information measurement techniques to analyze reported maintenance data. Failure data on two systems were analyzed: 1) the ASB-4 Bomb/Navigation System of the B-52, and 2) the MA-1 Fire Control System of the F-106. The ASB-4 data (flight-line reports) and the shop data for the MA-1 contained written descriptions of the malfunction symptoms. To make these data amenable to multivariate uncertainty analysis, a coding scheme designed to retain the grammatical form and content of these symptom reports was used.

see 1473 in front

DD FORM 1 JAN 64 **1473**

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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